Special STEEL Section

METALLURGIA

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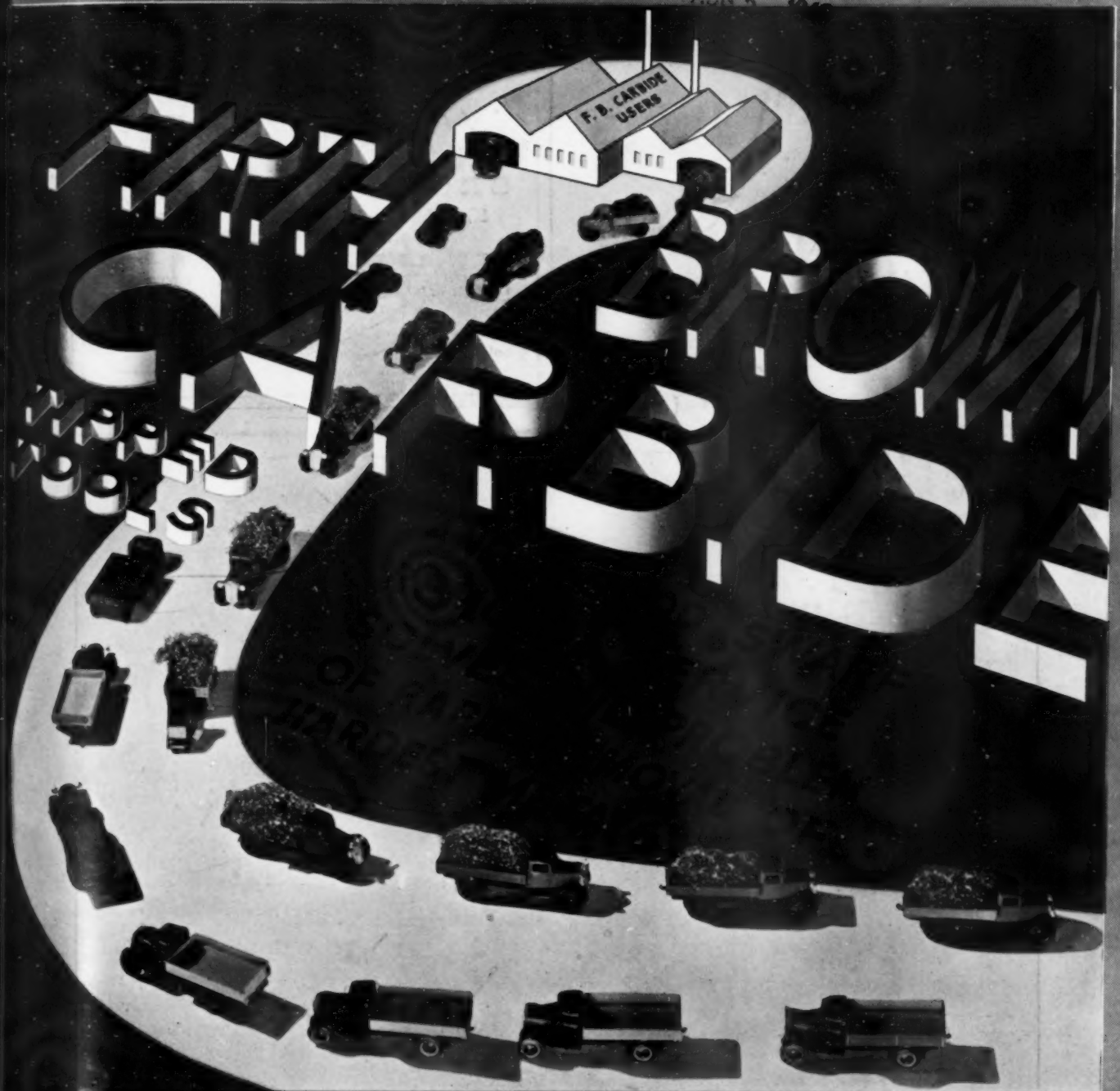

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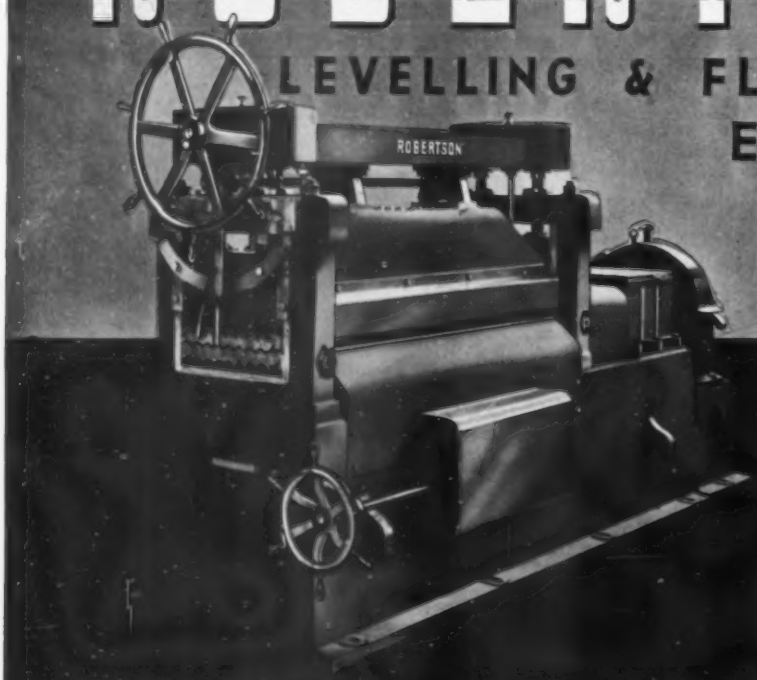

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METALLURGIA

The British Journal of Metals

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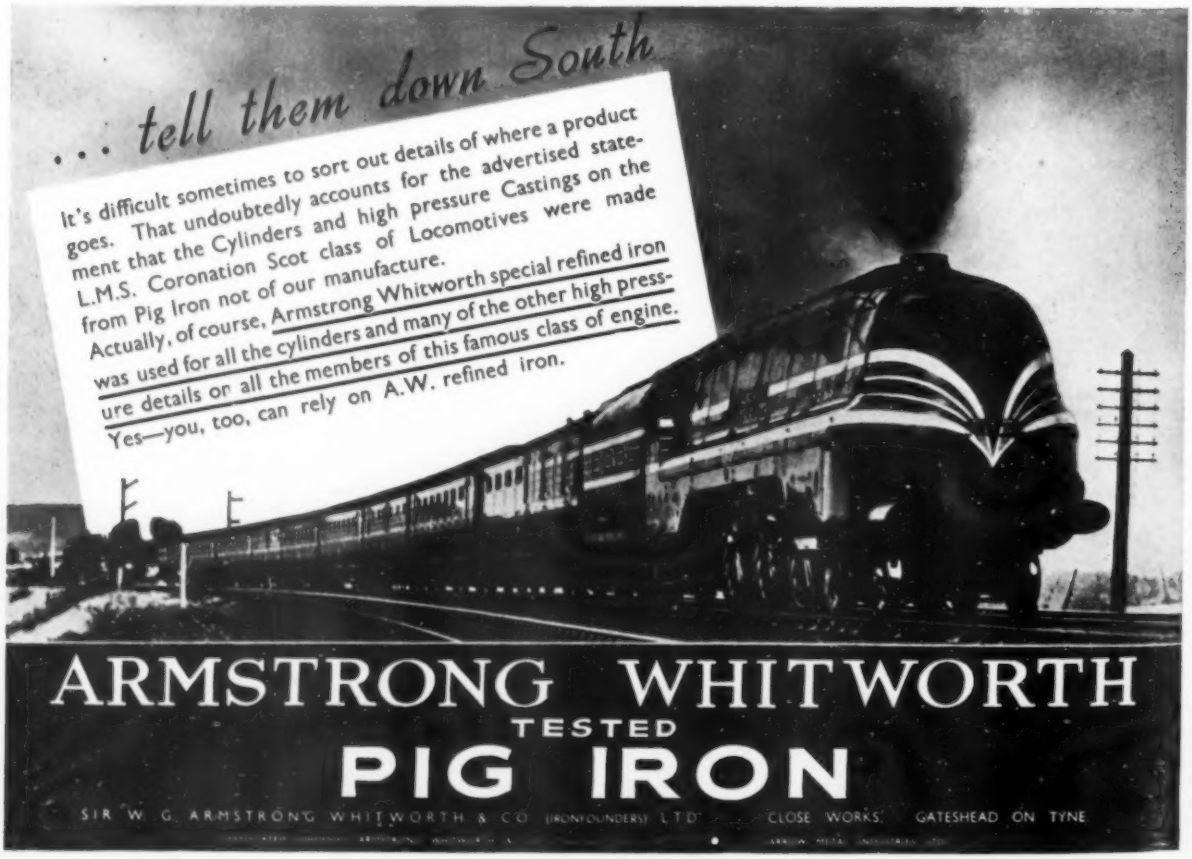
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METALLURGIA

THE BRITISH JOURNAL OF METALS.
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JULY, 1940. VOL. XXII, No. 129.

Jig and Tool Design for Anodising

By G. O. Taylor

Jigs are described which are typical of the tools that can be advantageously added to the equipment of an anodising plant. Their use increases the rate of production of articles which require to be anodised and effect a considerable reduction in cost.

THE increasing demand for anodised parts necessitated by the rapidly expanding aircraft industry has led to laying down many new plants for the anodic oxidation of pressings, spinnings, castings and forgings in aluminium and its alloys. Many firms still follow electroplating practice in that parts to be treated are "wired-up," using 18 or 20 S.W.G. pure aluminium wire. Where a large output of a variety of standardised parts is required this practice is uneconomical and restricts production capacity for the following reasons :—

(*a*) Considerable labour time is consumed in wiring and unwiring after treatment.

(*b*) The anodic vat often cannot be loaded up to the full capacity of the generating equipment available, as it is necessary to space the parts to be treated more than need be to avoid "burning" caused by the contact of adjacent parts set swinging by the air agitation employed.

(*c*) The wire is relatively expensive and can only be used once, unless more time is lost in stripping off the anodic film and straightening out the wire to allow it to be used again. Even so, the wire often becomes weakened following the first anodising, with the risk that parts may drop off during second usage.

Careful consideration given to the design of suitable tools and jigs in relation to parts to be treated will not only greatly speed up output by enabling larger tank loads to be anodised in safety, but will cut down labour expenses and enable wires to be dispensed with almost entirely, except in the case of an occasional odd job.

Properly constructed jigs have a long, useful life and will repay manufacturing costs several times over in a short time. The material from which they are constructed should possess good strength to enable rigidity of construction without recourse to use of thick sections, and should be of a composition amenable to anodising at the lowest possible current density, both to reduce power wastage and to avoid drawing away too much current from the parts suspended on them. In this connection the aluminium-magnesium alloys, such as D2, Birmabright, MG 7, etc., are worthy of consideration.

There are many types of jigs that can be usefully employed, and the constructional details and particular methods of use for each class are described below.

Bent Rod Jigs.—As implied by the name, this type of jig is quickly and easily made by bending $\frac{1}{4}$ in. diameter rod of "springy" temper to appropriate shapes. Figs. 1, 2, 3, and 4 show typical jigs of this type. In each case the top of the jig is bent over a piece of rod of the same diameter as the bus-bar on the anodic vat, and then pinched in to render the loop of spring-clip action.

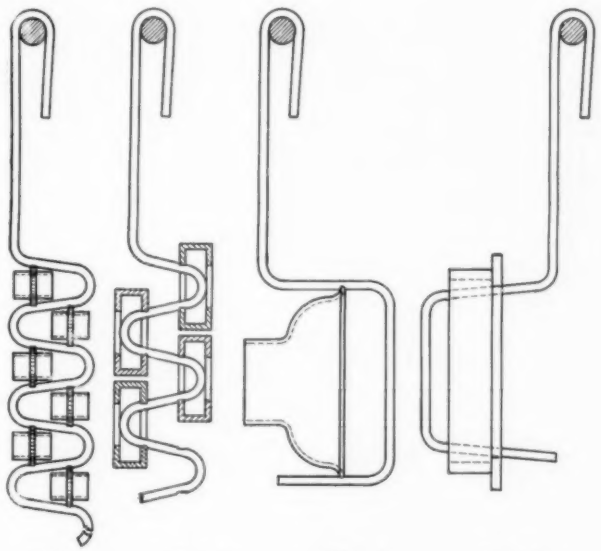


Fig. 1. Fig. 2. Fig. 3. Fig. 4.

Some typical anodising jigs.

Fig. 1 shows the jig adapted for the holding of a series of small parts inside the bends. Fig. 2 shows how such a jig can be made to hold a series of plates having a hole or holes in the surface. In this case the parts are held firmly in position by filing small nicks into the wire at the top and bottom of each bend with a triangular file. Fig. 3 shows a jig similarly nicked adapted for holding a sheet spinning, while Fig. 4 is of a jig suitable for holding ring-type parts.

The uses to which such simple types of jigs can be put are numerous, and it is obviously possible only to generalise. The length of the jig and the number of articles that each one will hold is governed by the current carrying capacity of the rod used and the current density absorbed by the articles under treatment. This can quickly be determined by an initial trial, and ultimately, as experience is gained, can be judged quite easily.

Straight Rod Compression Jigs.—The straight rod compression type jig is one of the most useful tools that the anodiser can have, since it has a wide range of uses and is easily made. With a jig of this description it is possible to treat almost any parts of moderate size, whether pressings, spinnings, forgings or castings, so long as there

is a hole greater than the diameter of the jig rod somewhere in the article. While the primary purpose of the tool is for the repetition treatment of large quantities of standardised parts, it can, nevertheless, be made to accommodate at one time articles of different shapes, as shown in Fig. 5, which further extends its range of usefulness.

Basically, the jig consists of a length of extruded pure aluminium round rod (A) of $\frac{1}{4}$ in., $\frac{3}{8}$ in., or $\frac{1}{2}$ in. diameter, which has one end screwed into a flat bar (B) to form a stop. The parts to be treated are loaded on to the rod from the previously discussed, but for the treatment of miscellaneous small parts of all types it is difficult to surpass, and the speed with which articles can be loaded and unloaded is surprising.

The main member is a $\frac{3}{4}$ in. square rod (B) of aluminium alloy of medium strength, such as D2, Birmabright, or 48. The "fingers" are made from duralumin wire $\frac{1}{8}$ in. in diameter which must be of "springy" nature. Commencing at a point that will be about 3 in. below the solution level, two $\frac{1}{8}$ in. diameter holes are drilled at 1 in.

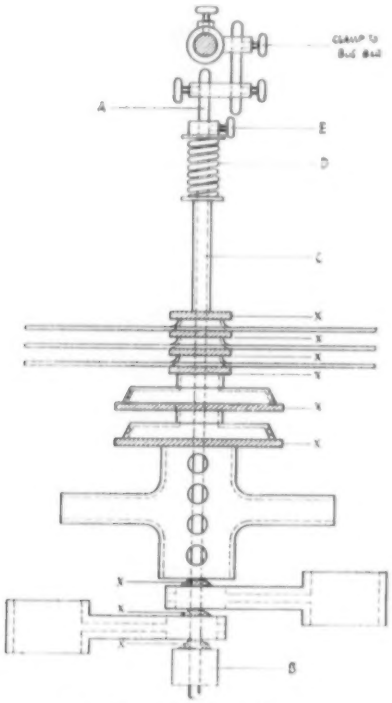


Fig. 5. Straight rod compression jig.

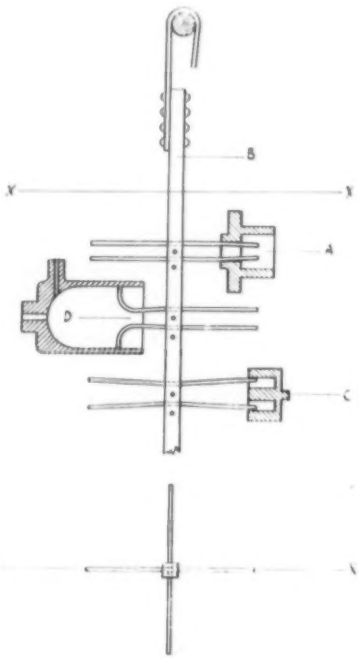


Fig. 6.—The finger grip tool.

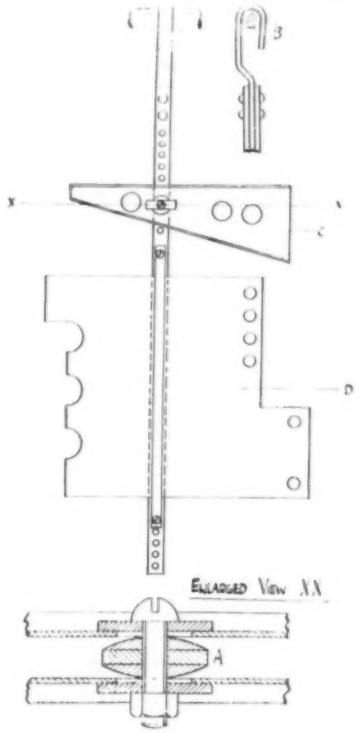


Fig. 7.—The bolt and bar jig.

end (A), and are separated from each other by one or more spacing pieces of flat or half-round section (X) drilled with a hole slightly greater than the diameter of the rod. (These are shown cross-etched for clarity.)

The number of spacing pieces to be placed between each part is determined by the distance required to ensure that parts under treatment cannot touch, and that sufficient space is available to permit free flow of the evolved gases. When the jig is loaded a spacing piece of tubing (C) is dropped on, then a strong steel spring (D) resting between two flat plates of stout sheet. The bottom (B) is then placed on the floor and the spring (D) is compressed as much as possible and held in position with the thumb-screw clamp (E), which can be of any suitable material. All parts are thus held tightly in contact and the jig can be connected to the vat bus-bar by medium of any suitable clamp arrangement.

The object of the tube (C) is to ensure that the spring (D) is carried well above solution level to avoid unnecessary corrosion.

At the conclusion of the actual anodising treatment, washing and, if desired, subsequent dyeing can be carried out with the articles still on the jigs, with considerable saving in handling time. To render the jig ready for use again all that is necessary is to remove the anodic film on the spacer bars and tube by immersing them for a few seconds in a hot solution of caustic soda. It is not essential that the main rod (A) should be stripped, as this functions purely as a supporting member.

Finger Grip Jigs.—The finger grip tool, shown in Fig. 6, requires a little more care in manufacture than the jigs pitch in the $\frac{3}{4}$ in. square rod. Then the rod is turned through 90° and two further holes are drilled, the first hole being at right angles to and midway between the two holes drilled initially, and the second hole then drilled at a 1 in. pitch, so that a group of four holes in two directions at right angles to each other is formed. This grouping of four holes is repeated at intervals of 3 in. along the entire rod.

Straight 10-in. lengths of the duralumin wire are then knocked through the holes so that an equal length projects from each side of the rod. If they are not quite tight they are then fixed firmly in position by peening in the appropriate places with a centre punch and hammer. It will be found that the wires so fixed can be squeezed together with the fingers, but will spring apart again when the pressure is released.

These "elastic fingers" can be utilised in many ways. Articles of tubular formation can be pushed over two of the wires, as shown at (A). The wires can be opened out, pinched in, and allowed to spring back inside a hole, as is shown at (C). If the ends of the wires are bent back as shown at (D) articles of "awkward" shapes can be quite easily held. Apart from the uses of individual pairs of wires, it will be found that it is possible to utilise wires in different groups where large articles of complex shapes are to be treated.

This type of jig, actually, is so versatile in its uses that it is not possible other than to give typical indications how it can be used. In practice, it will satisfactorily hold parts weighing anything from a fraction of an ounce to several ounces.

The Bolt and Bar Jig.—The jig shown in Fig. 7 is a further example of a " permanent " type of tool for which many uses can be found, particularly since it will accommodate large pressings of awkward shape and also castings several pounds in weight if the need arises.

The main member of this jig is a straight length of extruded flat bar 1¼ in. × ¼ in. of one of the strong alloys of the duralumin type. Two shorter lengths of pure aluminium half-round moulding are riveted one each side of this, at the top and bottom, as shown at (A). Before the half-round mouldings are fixed on, however, one of them is drilled at 1½ in. pitch with ¼ in. holes, so that after the

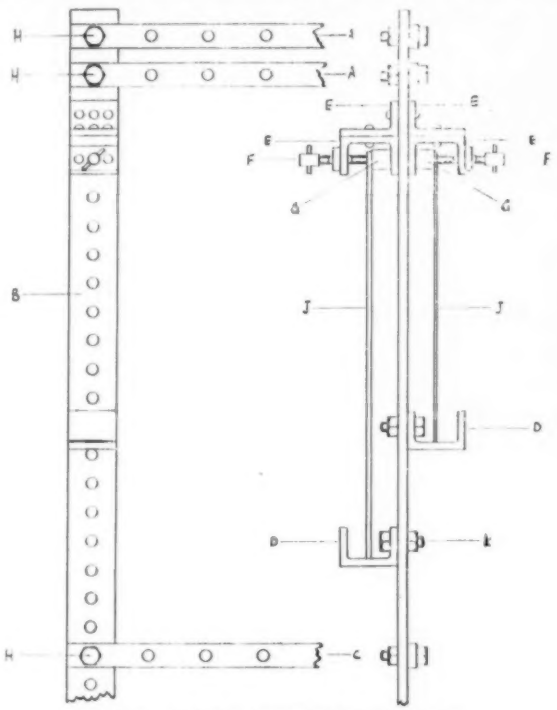


Fig. 8.—Jig for handling large sheets.

three sections are riveted together the drilling can be continued straight through the composite section with the assurance that the holes will be in alignment throughout. The completed member will then be of cross-section as at (A), but will have ¼ in. holes at 1 in. pitch.

The length of the bar will depend on the depth of tank in which the jig will work, but in any case the duralumin flat should be about 18 in. longer than the pure aluminium half-round sections, so that the projecting end of the bar can ultimately be bent over to form a spring clip (B) to fit over the tank bus-bars. The remaining requirements are a number of pieces of half-round section of miscellaneous lengths and a quantity of strong aluminium alloy ¼ in. metal thread screws or bolts, with nuts to suit.

With the aid of these, pressings of the type shown at (C) can be held against the main member in pairs, one each side of the rod, using one nut and bolt and two half-round bars. Large irregular shapes as at (D) that are not suitably perforated can be held with two bolts and a longer length of half-round section.

The half-round section should always be used with the rounded face contacting the article to be anodised, when it will be found that the point contact resulting, both at the main member and at the holding bar, will be practically invisible.

If two of the main members are joined with duralumin flat at the top and bottom to form a rectangular frame, long lengths of extruded sections or tube or the like can be handled with facility, and it will be seen that by taking advantage of both sides of the main member it is possible to accommodate anything from 20 to 40 lengths of section, depending on size and shape, on the single jig, with no fear of burning due to swinging contacts.

When handling repetition lots of medium size pressings, etc., all that is necessary between runs is to rub over the half-round faces of the main member with emery cloth to remove the anodic film. The nuts and bolts should not be stripped after the first anodising, and it is only necessary to remove the anodic film from the holding bars if very heavy current is being taken, and it is found that the two-point contact on the main member is not sufficient to pass it.

Jig for Handling Large Sheets.—Fig. 8 shows an arrangement for a frame jig designed for the handling of large flat sheets of varying lengths and widths. Basically, this jig is a frame capable of being closed or extended both lengthwise and in a vertical direction. The vertical members (B) are extruded flat strip, preferably in a duralumin type material for rigidity. The cross members (A) and (C) are from similar material, but can, if desired, be of smaller cross-section to avoid unnecessary weight. The horizontal members (A) and (C) are drilled with ⅜ in. diameter holes at 1 in. pitch, so that by removing the light alloy bolts (H) the vertical members (B) can be moved outwards or inwards, to increase or lessen the distance between them, as may be desired. At a point which will be two or three inches below the solution level, when the entire frame is connected to the tank bus-bar by any suitable means, are fixed the brackets (E), made by riveting together short lengths of light alloy angle and channels in the manner shown.

This composite section is firmly fixed to the upright member (B), preferably by riveting, and the channel section has round rod (G) screwed in at the position shown, and a stout duralumin turn-screw (F) working through a piece of thick section material riveted to the outside of the channel to form a longer tapped hole than would otherwise be available. This ensures adequate bearing for the screw (F), which is to hold the sheet (J) to be anodised firmly in contact with the stop (G). The weight of the sheet is taken up by the channel sections (D), which can be moved up or down the vertical member (B) by removing the light alloy bolt (K) and refixing the support in the requisite hole.

It will be seen that with a tool of this type it is possible to treat sheet of any length and width up to the working capacity of the tank by opening or closing the frame as may be necessary. The only attention necessary between baths of work is to remove the anodic film from the faces of the stops (G) and turn-screws (F) to ensure good contact.

Conclusion

The jigs described are typical of the types of tools that can, with advantage, be added to the equipment of an anodising plant. The small capital charge engendered in their manufacture will quickly be repaid by the increased rate of production made possible by the large number of articles that can safely be anodised per batch load, and the substantial reduction or elimination of costs for wire that can only be used once, or twice at the most.

It is obviously possible only to generalise on the tool forms, as different plants will have different requirements, but the basic principles described can be adapted and utilised to suit varying circumstances.

Experiments on the Pitting of Duralumin

AN investigation on the fitting of non-ferrous metals is described by Nishihara and Kori* by determining the amount of abrasion of duralumin cylinders when they are in rolling contact under lubrication, after every $2{\cdot}5 \times 10^5$ revolutions, until the abrasion increased suddenly and pitting occurred. The values obtained are compared with the fatigue stress of duralumin under compression and found to be nearly equal, so that it is concluded that the cause of pitting in duralumin must be the fatigue of the metal. Similar results were obtained with copper.

*Trans. Soc. Mech. Eng. Japan, 1939, 21, pp. 89-97.

Drawing of Alclad Strip

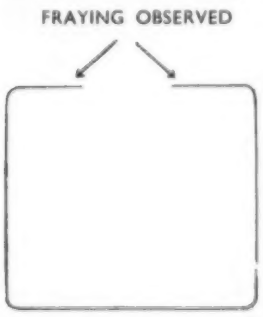
AN investigation recently carried out on the drawing of Alclad strip for aircraft components reveals points of considerable interest to all concerned with sheet forming. It was found that a section of the profile illustrated exhibited a tendency to crack during the drawing operation. The problem was therefore submitted to the Technical Advisory Service of the Northern Aluminium Company, who supplied the material.

A preliminary investigation revealed that the works personnel fully appreciated that somewhat greater power is required to draw the alloy to DTD. 390 than the L.38 alloy previously used for the purpose. Also, examination of the section revealed that the design stipulated radii sufficiently liberal to ensure easy drawing. A detailed investigation was therefore initiated to discover the root cause of the failure.

Mechanical tests taken on a specimen cut from the base of the channel indicated that the metal had retained the ductility imparted to it by the annealing treatment which it received prior to drawing, in spite of a certain amount of strain hardening to which it had been subjected in the drawing operation. These results pointed to the fact that the intrinsic qualities of the alloy were not responsible for the failure.

Such being the case, it was not considered necessary to recommend modication of the annealing practice followed, except to suggest the possibility—after making the necessary alterations to tools—of substituting solution heat-treatment for annealing. In this way, of course, the number of treatments would be reduced. Generally speaking, the advisability of adopting such a procedure will depend on the sequence of processes followed in any particular plant. It is, however, in most cases desirable from metallurgical as well as from production points of view.

The lubricant used (beeswax and tallow) was a most suitable choice, being one which is widely adopted. It is, however, of interest to point out that thick cylinder oils are satisfactory for the purpose. A further lubricant which has been used with considerable success is a chemically-neutral white soap, this being mixed with water to form a thick cream. An advantage of such lubricants is that they avoid the necessity for hot application.



In parenthesis, with reference to this problem of lubrication, it is important to note that the aluminium coating on Alclad alloys behaves in a different way from the harder surface of the uncoated high-strength alloys. One high authority indeed, has stated that the lubricating effect of the aluminium coating greatly facilitates the production of components such as aircraft fuel tanks, etc.

Microscopic examination of the broken portion revealed that cracking commenced at the extreme edge of the section, where considerable fraying had occurred. It was also found upon examination that the drawing tool used did not possess the finish which it is generally found advantageous to provide on equipment of this type. This fact was borne out by the appearance of heavy drag marks on the inside corners of the section in particular.

The result of these examinations was to confirm an opinion which had previously been expressed, namely, that cracking had emanated from a notch in the extreme edge of the section. This was undoubtedly due to the fraying caused by excessive crowding of the die at the edge of the sheet. Such a fault would be eradicated only by carrying out suggested modifications to the die, or, alternatively, by a suitable reduction in the width of the strip.

In view of the extent of the deformation which was produced in one draw, it was pointed out that the lead radii at the back of the die would be called into action. Consequently it was recommended that these radii be made more liberal. Also, since a contributory cause of the failure was considered to be the high drag produced by the roughness of the tools, it was suggested that the sizing surface, the lead radii and all draft surfaces be given a high polish.

The adoption of these recommendations resulted in complete elimination of the trouble, no further instances of such failure having been reported in spite of the fact that a vast number of such sections has been produced.

Bending Sheet Aluminium to required profile

Another problem concerned the bending of aluminium sheet to selected profiles for aircraft construction purposes. In one particular instance the design detail of the aircraft was such that the bending of certain members involved the works in considerable labour, high costs, and excessive waste in the form of scrap. For example, longeron members from 5¼-in. wide strip, of thickness 14 g., and of length 6—10 ft., were being annealed, bent up along one edge by means of a folding press and normalised, the bending radius being 2 tons. It was found that the free edge was being so badly buckled that in some cases labour to the cost of 2s. 6d. per piece needed to be expended in straightening. Even then a proportion only of the parts was rendered usable. Forming immediately after solution treatment had also been tried, but here again the bowing and buckling in treatment was too great to enable a parallel edge bend to be made.

This problem was solved by pointing out that a bend radius of 3 tons would be necessary to enable a cold bend in the aged condition to be made. Such a bending radius, it is important to note, complies with the requirements laid down in the Air Ministry Memo. (A.M. Memo. 338) on the subject. Design considerations which involve sharp bends are undoubtedly of some importance, but it is of great importance that works manipulation be assisted to the maximum degree in the present intensive aircraft construction programme.

Metal Compounds of Helium

RELATIVELY stable complexes of helium with platinum, iron, palladium, bismuth, sodium and uranium have been isolated in the last few years by Damianovich. The principle of his method is the passage of a current between electrodes of the metal in a helium atmosphere of very low pressure, and the success of the process is largely governed by the voltage and the degree of vacuum. In the case of bismuth, for example, the helium complex is deposited upon the walls of the tube when the discharge is passed at 700–800 volts, and the helium pressure is 0·4–1·2 mm., whereas no fixation occurs when the tension and pressure are respectively 1,000 volts and 1·5 mm. Another factor interfering with the reaction is the traces of hydrogen arising from moisture or decomposed stopcock grease.

The helium-sodium complex forms a grey film on the walls of the tube round the cathode and on the surface of the sodium. Its stability is such that helium can only be driven off by heating to the volatilisation point. Platinum-helium forms a white-to-brown film. Uranium-helium is inferior in stability to the platinum, iron or palladium complexes, a property which is believed to account for the non-radioactive origin of helium in rocks and gas wells.

Damianovich has determined the helium content of several metal-helium compounds. The uranium complex contains 6–9 cu. mm. helium per mg. metal; the bismuth complex contains over 7 cu. mm. per mg. metal.

Damianovich and Christer. *Rev. brasil Chim.* (São Paolo). **6**, 72 (1938).
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METALLURGIA
THE BRITISH JOURNAL OF METALS.
INCORPORATING "THE METALLURGICAL ENGINEER"

The National Physical Laboratory

Review of Progress in 1939

THE work of the National Physical Laboratory in normal times is directed towards four main functions: the assistance of industry in its immediate problems by advice and experiment, research of longer range which aims at opening up new technical possibilities for industry, the testing of instruments, and the maintenance of standards on which all physical measurements depend. With the outbreak of hostilities entirely new conditions have arisen, but there has been no falling off in the routine of giving advice and help to industry, and much of the work previously done in other directions has been expanded considerably. Many new problems have been submitted and a number of members of the staff have been lent to other establishments, in consequence the staff has been redistributed among the departments of the Laboratory to a considerable extent, and there has been an alteration in the order of priority in which the researches of the Laboratory are regarded. It is important to note, however, that the essential peace-time function of tendering advice and help to industry on scientific and technical problems has been fully retained.

Since its inception in 1900 the Laboratory has grown to considerable dimensions, and the importance of its work has progressed in similar proportion. The work covers a very wide field, including all branches of physics, electricity and magnetism, radio communications, metrology, engineering, metallurgy, aeronautics and ship design in relation to form and propulsion. Its contribution to fundamental knowledge in these various sections has been very considerable, and the Report of the Executive Committee for 1939,[1] presented to the General Board, indicates that, in addition to further work of a fundamental character, the work of the Laboratory continues to be of importance in establishing facts which can be applied to industry. The Report deals with items on the research programme which have been completed, or which have reached a definite stage in their progress, and a brief reference to some of these will be of interest.

The study of the thermal properties of metals has been continued. The work includes the determination over a wide range of temperature of the specific heat of very pure iron. Further work has been carried out for the Alloy Steels Research Committee on the specific heats, expansion coefficients, and thermal and electrical conductivities of carbon steels. A precise determination was made of the boiling point of selenium to provide a fixed point in the part of the International Temperature Scale between the sulphur and gold points.

Interesting results have been obtained by the application of X-ray crystal analysis to the structure of steel under fatigue stressing, and to the investigation of metals when cold-worked. Much of this work has been done in close collaboration with the Engineering Department, and the combination of the X-ray analysis of structure with mechanical tests has provided a valuable technique for fundamental investigations of the strength of materials. Attention has been devoted in particular to the case of single crystals of aluminium under cyclic torsional stresses, as well as to that of specimens composed of several large crystals.

An empirical relationship has been determined for the fatigue resistance of steels under combined bending and torsional stresses of varying proportions, and the theory has been extended to brittle materials and to cases where stress concentrations are introduced by discontinuities such as V-notches, holes and splines. Further research has been carried out on steel wires subjected to various forms of surface treatment. The study of the creep of carbon steel under combined stresses, as well as the researches on the creep of high-temperature alloy steels, have been continued. Much work has been carried out on problems arising out of the use of cylinders for the transport of gases under pressure; the work has been concerned with the failure of cylinders under service conditions, and with the properties of new materials and methods of construction.

The main researches conducted in the Metallurgy Department which were in progress prior to the year under review have been continued under the guidance of the Metallurgical Research Committee of the Executive Committee, with the helpful advice of the Alloys Sub-Committee of the Aeronautical Research Committee in the work on light alloys. The research on aluminium alloys has largely been concerned with the ageing of copper-aluminium alloys, while that on magnesium alloys has been directed to the improvement of the mechanical properties by suitable forging treatment. In the latter work X-ray studies have been helpful in correlating the structure with changes in the mechanical properties under the various types of treatment.

The study of iron alloys, using very pure materials, has been continued. In plant recently installed for the preparation of highly purified iron, material with impurity between 0·001 and 0·006% is now being regularly obtained. This material has been used for the determination of the iron-nickel constitutional diagram in the neighbourhood of the delta phase. Melting-point determinations of the very pure iron have yielded the value 1,533° ± 5° C. Further work has been completed for the Alloy Steels Research Committee on the temperatures of transformation of a number of alloy steels.

Research on materials at high temperatures is being continued for the British Electrical and Allied Industries Research Association, with which the iron and steel industry is co-operating. Further work, of a more fundamental character, is also in hand as part of a research programme of the Laboratory. A series of reports to the above Association, which are being prepared, relate to the problem of intercrystalline cracking, the influence of further elements on molybdenum steels, and the effect of initial condition and heat-treatment. In the Laboratory research programme the work on the effect of carbon in steel up to 1·2% over the temperature range 350° to 950° C. is approaching completion. In this work the rate of graphitisation of various steels has also been studied, since this effect, as well as that of spheroidisation, is found to be important. With the increase of temperature and of time of testing, carbon does not impart the great increase of strength that is found at atmospheric temperature. Tests on molybdenum and carbon steels are now being

[1] The National Physical Laboratory—1939 Report. H.M. Stationery Office, York Street, London. Price 2/6 net.

carried out in the creep apparatus in an atmosphere of oxygen-free steam, and further work on the relationship of age-hardening to creep performance has been started, using rolled duralumin instead of the nickel-silicon-copper alloy previously studied.

In analytical work special attention has been given to the estimation of carbon in highly purified iron, sulphur in iron, and graphite in low-carbon steels which have been subjected to prolonged heating. Improved methods developed at the Laboratory for the estimation of total oxygen and for the analysis of inclusions in steel are included in the "Eighth Report on the Heterogeneity of Steel Ingots."[2] Later work has included the examination of the inclusions in a rimming steel.

Each department has contributed to the advancement of scientific knowledge, and although much of the work is of a fundamental character it is of immense importance to industry since it is concerned with new problems, as well as old problems for which solutions have not been found. It is gratifying to note that the Laboratory still retains a great deal of its peace-time character, that it is continuing to facilitate the progress of industry by assisting in providing a fuller knowledge of materials and structures, and maintaining its essential function of tendering advice and help to industry on scientific and technical problems. It is hoped that industry will continue to respond by seeking the assistance of the Laboratory in the solution of the many problems it is called upon to face.

Speeding Up Production

"He who attempts to invade the shores of the British Isles dare not, and must not, regard his expedition as one rounding off a series of European conquests, but rather as the beginning of a great and terrible adventure which offers not the slightest prospect of final success against an Imperial system and great continents possessed of illimitable man-power and resources. They command the oceans and spirited peoples who do not know defeat, and if necessary will blockade the whole continent of Europe so that Germany and her allies would perish in their very triumph."

Imperial Policy Group's "Memorandum of Information."

IN this war, as in the last, it is in the workshops as much as on the battle fields that Germany's attempted conquest of the world will be frustrated. The question of labour reinforcement to facilitate the production of supplies of munitions has been, and is being, given careful consideration by responsible ministers in the Government and it is assumed by the general public that every effort is being made to increase the speeds at which essential work is completed, but there are many aspects of speeding up production which are not concerned with additional man-power in the shops and yet are of equal importance. That a state of National emergency exists is recognised by the general public, an indication of which is shown by the remarkable response to the request for aluminium articles and there is ample evidence that the men and women in the workshops and factories are not sparing themselves to speed up output, but frequent delays caused by Government officials are very disquieting and create a doubt as to whether the condition of emergency is fully appreciated by the official mind.

It may be admitted that there is much thinking and foolish talk about "red tape." Actually the Civil Service is an admirable institution more free of corruption than in other countries and in peace time it attracts men of outstanding merit. Let us recognise wartime as abnormal and appreciate the great difficulties of adapting a peace-time organisation to supply its abnormal requirements. In a totalitarian state it is an easier matter because there are no consideration of personal rights or agreements. In this respect the totalitarian state approximates to the slave state. Actually war-time control should temporarily be in the hands of business or technical men who have dissociated themselves entirely from business. It is of the greatest importance that, while at least temporary reform of the Civil Service may be necessary, men and firms who have axes to grind shall be eliminated. Vexation is voiced frequently at the delays caused by unimaginative organisation and rigid rules that retard production but it is not always easy to strike that middle course which gets maximum production without quality being impaired.

Apart from the incidental sprags in the wheel caused by inelastic official procedure the production problem can be divided broadly into three compartments which are:— Firstly, the supply of raw and semi-finished material; secondly, the manufacture of equipment; thirdly, the labour supply. Very little can be said here about the flow of material and the quantity of equipment of all kinds manufactured is governed very largely by the amount and the quality of the labour available. Mr. Churchill in his inspiring broadcast talk to this country and America on Sunday, July 14th, quite frankly stated his opinion that it would be a long war and that, in all probability, in 1942 we should take the offensive. Long period production arrangements must therefore be made and the sooner war-time life is accepted as normal the better it will be for all classes. The Government decision that all professional engineers should register may have appeared belated but its value can easily be exaggerated. Most technical men are already pulling their weight in the boat. This class of labour can never be as mobile as workshop labour because it cannot by its nature as quickly adapt itself to varying conditions. We refer particularly to research workers but the stricture applies almost with equal force to those employed on more routine work. Technical engineers apart, it is doubtful if the best use is yet being made of workshop labour. Employers are not always willing to release men who are temporarily employed on normal hours. Men also at times make difficulties. Fortunately labour movement is more smoothly effected now than a month or two ago.

How can the labour supply be augmented? That is a question of paramount importance. The present Government has been little more successful in solving the unemployment problem than the last government. There are still some three-quarters of a million people idle. These should all have been absorbed many months ago. For their own sakes, apart from national necessity, these people should be given work. It is nonsense to say that they are unemployable. There is much unskilled and semi-skilled work in engineering shops that these people could do. It would give them an opportunity of winning back their manhood. The instructional schools, if the right type of instructor is employed, will do useful work. But what about part-time workers? Mr. Bevin recently addressed himself to housewives who might give one or two days a week to relieve factory workers. He should realise that there is a considerable number of engineers in this country who are now in other businesses but would be willing to give week-ends and evenings to relieve tired men. These men, many of them highly technical and highly skilled, would quickly regain their skill as technicians or workmen and would be a great asset; their spare time would be better utilised in this way than as special police, voluntary A.R.P. workers or Local Defence Volunteers. This seems such an obvious reservoir that it is surprising that no attempt has yet been made to organise their labour. That a scheme for part-time skilled men will come is fairly obvious but it ought to be undertaken now. In considering this matter of speeding up production there should be a realisation of the fact that only for a limited time can men work long hours seven days a week and we have Mr. Churchill's opinion, which most men share, that it is going to be a long war. The organisation of a body of relief workers is perhaps our most urgent need. It should not be forgotten for a moment that the greatest National emergency cannot make machines of men. Continuous overtime is costly because it is less efficient.

2 Iron and Steel Institute. Special Report. No. 25.

The Practical Side of Blast-Furnace Management, with Special Reference to South African Conditions

A brief description of the two South African blast-furnace plants is given by R. R. F. Walton in an advance copy of a paper to be presented at the September meeting of the Iron and Steel Institute. Details of the furnace lines are given, and the raw materials used are discussed. The handling and operation of the furnaces are described, and in this abstract attention is directed to these aspects of the subject.

THE blast-furnace plants of South Africa comprise the Pretoria plant of the South African Iron and Steel Industrial Corporation, Ltd., and the Newcastle plant of its associated company, African Metals Corporation, Ltd. There are two furnaces in the former plant, each of which has lines and dimensions shown in Fig. 1. They are equipped with McKee revolving tops. Hearth cooling consists of solid-drawn steel pipes cast in cast-iron staves, surrounded by a 1½ in. mild-steel jacket. The bosh is of the banded type, cooled by copper plates, while the tuyere belt is a 1 in. mild-steel jacket pierced to take 10 tuyeres and four rows of cooling plates. There are seven rows of duplex copper plates above the lintel. The furnace charging is carried out by double skips, electrically driven on an inclined hoist. Coke is drawn from coke-bins on either side of the hoist into automatic weigh-hoppers, which deliver into the skips. Ore and flux are handled in electric scale-cars of 10 tons capacity. The scale-car driver operates the whole of the charging system.

The metal is handled via cast-iron runners into 60-ton ladles, while two slag notches are provided. These consist of a cast-iron cooler with steel pipe coil cast in, an intermediate copper slag-cooler and a 2 in. copper monkey. The slag is delivered into steam-tipped slag ladles of 175 cub. ft. capacity. Normally, molten metal is delivered direct to the melting shop, but when necessary the whole output can be handled in a two-strand pig-casting machine.

The Newcastle plant comprises one blast-furnace and possesses lines and dimensions shown in Fig. 1. The hearth and bosh jackets are of mild steel cooled by external sprays. In the mild-steel tuyere belt there are eight tuyeres and three rows of copper plates. There is one row of copper plates above the lintel. This furnace is charged by means of barrows carried by a double-cage vertical hoist. Most of the materials are delivered broken to size, but a small crushing plant is installed to deal chiefly with dolomite. The barrows are filled from concrete bins, the weight is adjusted and the barrows are hoisted to the top. Here they are dumped via a small bell on to the main bell and thence into the furnace.

Raw Materials

Unlike general European practice, where moderate or poor ores are usually smelted with good coke, South African conditions call for the production of iron from exceedingly rich ores with poor coke. At Pretoria the usual ore mixture contains 64·0% of iron and 6·1% of silica, comprising Pretoria and Thabazimbi ores, while the coke contains 16% of ash and only 82% of fixed carbon. About 3,050 lb. of ore and 1,530 lb. of coke are required to produce a short ton of metal. It will be seen, therefore, that the greater proportion of the slag-forming materials arises from the coke, and as this is only liberated when combustion of the coke takes place, there can be no comparison between the slag in the bosh zone and the final slag flushed from the furnace. It might be expected that the extremely limey slag at the top of the bosh would cause trouble, and that this is not so is partly due to the small weight of slag arising from the ore-bearing materials. Fortunately the two ores used contain 0·5% and 4·0% respectively of alumina, so that it is possible to balance the two to produce a slag containing about 16% of alumina, which gives a very free-flowing slag.

The iron ores used at Newcastle are Thabazimbi ore and ores from local surface deposits. The latter vary from 50 to 58% of metallic iron, with from 6 to 10% of silica, and are limonites. It is necessary to add sandstone to mixtures of these ores to produce a sufficient slag volume for effective desulphurisation, but this presents no difficulty. Transvaal dolomite, similar to that used at the Pretoria works, is the regular flux, while for phosphoric foundry irons, with up to 1·6% of phosphorus, phosphate rock is added to the burden. The coke used is beehive and by-product coke produced in Northern Natal, and delivered to the works by rail. For the production of ferro-manganese the same coke and dolomite are used with manganese ore from the Postmasburg district of the Cape Province. The latter averages 50% of manganese, 7% of silica, and 5–6% of iron, and is in dense lumps, which are broken to about 5 in. size for blast-furnace use.

Handling of the Furnace

Preparation of the Furnace.—The following method of preparing and blowing in the furnace has been standardised in South Africa :—When the brickwork is finished and the top gear in position, the tuyere coolers are rammed up from the inside with ground fireclay and brick, thoroughly packed in. A fire is then made on the hearth, the cooler apertures being bricked-in with a loose brick in each to allow of adjusting the draught. In the case of the Iscor furnaces where there is always one in blast and the gas-golder maintains continuity of pressure and supply blast-furnace gas is led into the fire through a 3-in. pipe after a couple of days. At Newcastle, where there is only one furnace, the fire is fed with coke and gently blown with compressed air. This drying is continued for 14 to 21 days, and meanwhile all the cooling plates are carefully pointed up on the outside with refractory cement.

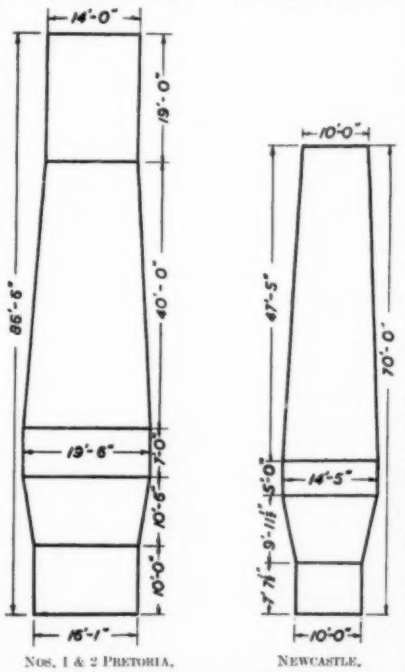


Fig. 1.—Lines of South African Furnaces

After firing has finished and the brickwork has cooled

down, about 3 in. of coke and tar mixture is rammed on the hearth in the shape of a saucer, to cover the horizontal joints where the brickwork is corbelled back to the same diameter as that of the wall of the well. A 6-in. pipe is placed in the tap-hole, about 3 ft. inside the well and extending about 4 ft. down the tapping-trough. This is rammed around with tap-hole clay from inside and outside. Four 1½ in. holes are drilled in the pipe so that it can be turned to keep it free in the hole and to withdraw it later. Coke is then thrown in by hand to the level of the bottom of the tuyere arches, and all tuyeres but one are put into position. Three sacks of coke, one on each side and one on top, are put around each tuyere to protect it when filling begins from the top. Likewise, old sleepers are placed against the bosh wall to protect the brickwork. The last tuyere is now put in place, and a little kindling-wood and shavings are put in front of the nose of each tuyere. The blowpipes and goose-necks are now fitted, and filling begins from the top.

When the furnace is full to about 20 ft. from the top, the distribution is examined by getting into the furnace through the big bell, which should be propped open. Care must also be taken that the water-seal or other valve isolating this furnace from the common cool-gas main is not leaking. Filling proceeds to 5 ft. below the big bell, and the furnace is ready for lighting. The water supply to the various cooling members is adjusted, each tuyere and tap-hole is lighted with hot bars and hot blast is put on at about 10,000 cub. ft. per min. for half an hour, the gas escaping through the bleeders and a little steam being turned into the main dust-catcher. After half an hour the blast is taken off, the tuyere lids are opened, and the furnace is allowed to draught for 24 hours. Blast is then put on again, and the gas is ignited at the pipe in the tap-hole and allowed to burn there for about 2 hours. The pipe is then withdrawn and the tap-hole plugged with the mud-gun. The gas is now of sufficient volume and quality to be put into the system. The water-seal at the outlet of the Vortex is emptied, and each vessel and main is purged in turn until the gas is right through the system, when the valve to the clean gas main is opened and the operation is complete.

General Operation.—The filling and distribution require careful watching and checking. Charging must be regular and the furnace kept as full as possible—to about 3 ft. below the big bell when in the open position. In addition to the automatic stock-line recorder, two other trial holes are provided, and it is customary to check up on these regularly to ensure that the distribution is even and the stock is level in the furnace. The coke charge is as large as possible, consistent with the capacity of the bell and hopper, as it is found that most furnaces work better the bigger the coke charge. At Iscor the coke charge is 10,500 lb. charged in four skips on the first bell, followed by two skips of ore and one of flux on the second bell. At Newcastle the coke charge weighs 4,800 lb. charged on the first bell in six barrows, followed by six barrows of ore and three of flux on the second bell.

It is the author's practice, so far as possible, to keep both the burden and blast volume constant for any one grade of iron and to make all necessary adjustments by alteration of the blast temperature. For any furnace there is an optimum blast volume, which can only be determined by experiment. When this has been fixed the burden is adjusted so that normally there is ample reserve of blast temperature in hand. The foremen have only to adjust this to keep the furnace on a constant grade of metal. When making basic metal for the open-hearth plant the furnaces often run for months on end without alteration of blast volume or burden, keeping the product constantly between 0·5% and 0·9% of silicon. The practice is admittedly more difficult where the use of several different ores necessitates changes of burden, but the practice often met with of changing the blast volume to meet variations in slag composition and furnace conditions is obviously unsatisfactory.

Hanging and Slipping are very rare occurrences when working to the method described. Hanging usually begins because of the furnace running too hot or too cold. The appearances of the crude gas, the tuyeres, and the slag at once indicate in which direction the furnace is swinging, and suitable adjustment of the blast temperature, with gentle checking of the furnace, will overcome it in the early stages. If possible, the furnace is allowed to slip on its own by adjustment of the blast temperature, but if checking is necessary, it is accomplished by signalling the blowers to ease down, with the snort-valve shut. This ensures a cushion of blast to prevent the burden from slipping heavily into the converging lines of the bosh and jamming tightly, so that the gas cannot penetrate the coke and slag in the bosh. This condition is recognised by the difficulty of forcing a bar through the tuyeres. A further danger in the sudden slipping of the furnace is the possible loss of tuyeres due to slag or metal being forced up to them.

Incorrect tuyere size for the particular furnace and volume of air blown will also cause irregular working, due to pillars either between the adjoining tuyeres or in the centre of the furnace. Tuyeres of different length or diameter will correct this, but, consistent with regular working, tuyeres should be as short as possible. To illustrate this, Pretoria No. 1 furnace worked throughout 1938 and 1939 with 12 in. × 5 in. tuyeres of standard design, and the average life per tuyere was 429 days. During the same two years No. 2 furnace, working on the same burden and grade of metal, with 15 in. × 5½ in. tuyeres, had an average tuyere life of 203 days. Both furnaces worked freely and well, and there were no signs of pillars or scaffolds. Both sizes of tuyeres were of the same general design and supplied by the same maker. The water strainers at the furnaces are changed over and cleaned regularly, and the individual cocks for the cooling members are of the three-way type, so that they can be flushed regularly.

Water Leakage.—With the multiplicity of cooling plates, etc., in a blast-furnace, the difficulty of detecting leakage from any one member often arises, especially as the water is sometimes so unkind as to appear far away from the place affected. The following experience will illustrate this: About midnight, on December 13, 1936, water began to come back around Nos. 2 and 3 tuyeres on No. 1 furnace. No. 1 tuyere is over the tap-hole and the ten tuyeres are numbered clockwise. These tuyeres were taken out and found to be intact, as were the corresponding coolers. Meanwhile, with the blast off, water began to appear at tuyeres and plates all round the furnace, and a trickle of water flowed down the tapping-trough from the side of the tap-hole. A systematic search was thus necessary, and this was carried out by putting a piece of hose-pipe on each outlet in turn. This was bent into a **U**-tube, the feed-cock turned off quickly and the water in the **U**-tube watched to see if its level sank. By this method the cast-iron slag-coil was found to be leaking, though no water appeared at the slag-notch. This coil was changed, and the water at the tap-hole began to grow less, so that the furnace was prepared for restarting. The tap-hole was naturally cold and hard, and while burning it out with oxygen water began to flow freely through the tap-hole, to the extent of a stream about 1½ in. deep in the trough. The furnace was again stopped and the systematic examination continued on the plates, etc., not previously tested. Eventually on trying the **U**-pipe on the outlet from the hearth jacket stave under No. 6 tuyere, this member was found to be leaking badly. In a few minutes after turning off the water the stream at the tap-hole disappeared. Fortunately a good coke blank, followed by a lighter burden, had been charged after the first stoppage, and the furnace was quickly normal again. The peculiar feature of this trouble was that the source of the water running from the tap-hole was 180° away, and yet found its way around the furnace.

Use of Dynamite.—Another personal experience of an unusual nature may be of interest. On December 1, 1938, the author was called to the Newcastle furnace, which at the time was making ferro-manganese. The furnace was badly "limed up," dead cold, and making no gas. There

had been a stoppage on November 28 to clean out the gas mains. On re-starting, the steam was low and only slack blast could be blown. There was not enough gas for the stoves, and the furnace got colder as the blast temperature fell, and on the author's arrival the position was desperate. It was arranged to charge a coke blank and put on an iron burden, but the furnace was not taking the blast, and little charging could be done. The usual procedure using sand, oxygen and oil was tried, and the three front tuyeres were kept open for some time and several lots of half-fused material got out of the tap-hole and slag-notch. In spite of all efforts, these tuyeres were finally lost on the night of December 4. They were again burnt out with oxygen, but could not be kept open, and it was decided to blast out the solid material. All tuyeres and coolers were taken out, and blasting started in the slag-notch and tap-hole, 36 sticks of gelignite in the slag-notch and 24 in the tap-hole This was continued all night of the 5th, the lumps being removed through the tap-hole after each blast. During December 6 all tuyeres were dynamited out, and it was then obvious that it was solid up in the bosh. On December 7 a 1 ft. 6 in. hole was cut in the shell about 2 ft. 6 in. above the lintel, and on drilling through the brickwork good hot coke was found. A hole was then cut about half-way up the bosh, and heavy charges—96 sticks in one case—were fired. Eventually the bosh was blasted clear and the dead material raked out of the tuyeres. Good hot coke then came down and filled the bosh. Plates were welded over the holes cut in the shaft and bosh, and the furnace was prepared for restarting. It got away at 8 p.m. on December 8, and gas was in the stoves at 9-30 p.m., and the trouble was over.

General

Both in the Transvaal and in Natal the bulk of rainfall occurs in the summer months—October to March—and mostly in the way of heavy thunderstorms. On occasion 4 in. or 5 in. of rain may fall in as many hours. It is necessary therefore to provide ample storm-water drains and to see that these are kept open. All low points, such as stock-house, skip-pits and weighbridge sumps, which cannot be drained into these sewers, must have pumps or other apparatus installed. During these periods of heavy precipitation the furnace burdens must be adjusted to allow for absorbed moisture, which is often very heavy.

Resistance of Hard Metal Alloys to Oxidation and Chemical Attack*

TUNGSTEN carbide and similar high-melting alloys have gained a reputation in the past decade as hard-wearing tool alloys. The possibility of their employment as components of chemical plant is now envisaged as the result of a series of tests on their behaviour when exposed to air, sea-water, acids and alkalies at various temperatures. They might be used, it is suggested, for valve seats and cones, bearing linings and pipe lengths.

Action of Air.—These alloys are, of course, perfectly stable at anywhere near the ordinary temperature. At elevated temperatures, however, serious oxidation is found to occur, particularly in the case of alloys containing a small percentage of metallic binder (cobalt). The following table shows the loss in weight of a series of alloys expressed as grams per sq. cm. per hour. This loss was arrived at after test panels were exposed to a current of hot air in a horizontal electric furnace, and the oxide layer carefully removed by brushing at the close of the test period.

Oxidation temperature ° C.	Tungsten carbide containing 6% CO.	Tungsten carbide containing 6% CO, and 15% TiC.	Boride alloy.	Cromium. carbide alloy.
600	0·4	0·05	—	—
800	44·0	13·5	0·01	0·01
900	67·6	24·5	0·07	0·06
1,100	—	—	1·38	1·51

It will be seen that tungsten carbide with a cobalt binder cannot be safely used beyond 600° C. in presence of air. Borides and chromium carbides show a much higher safe limit (800° C.), but against this stands the fact that they are inferior in mechanical strength to the tungsten carbides, and cannot be used under conditions exposing them to great impact or tensile stress.

Action of Sea-water.—In one series of tests the panels were immersed for a total period of three months, the water being changed every two days. Corrosion was found to be negligible, amounting to only 0·04 gram. per sq. cm. over the three-month period in the case of cobalt-containing tungsten carbides. The finely-pitted surface observable under the microscope after exposure may be due to preferential corrosion of the cobalt.

Action of Mineral Acids and Alkalies.—The panels were immersed in the liquids for 50 hours, and tests were run both at ordinary temperature and at boiling temperatures. Losses in weight at the ordinary temperature are given in grams. per sq. metre per 24 hours :

Corrosive solution.	Tungsten carbide (6% CO).	Tungsten carbide (6% CO & 15% TiC).	Tungsten carbide (no binder).
30% nitric acid	69·5	—	5·9
20% hydrochloric acid ..	26·5	9·0	1.2
50% sulphuric acid	1·2	—	—
20% hydrofluoric acid ..	15·0	17·0	1·3

Since the auxiliary metal used to bind the carbidic components is generally soluble in acids, the behaviour of hard alloys is largely governed by the resistance of the former metal. This consideration is clearly demonstrated by the relatively high resistance of cobalt-free tungsten carbide to all the acids in the preceding table. Of particular interest is the very low corrosion by hydrofluoric acid.

Corrosion at boiling temperatures was naturally much more severe, as is evident from the following typical figures (loss in grams. per sq. metre per 24 hours) :

Corrosive solution	Tungsten Carbide (6% CO).	Tungsten carbide 15% TiC).	Tungsten carbide (no binder).
20% hydrochloric acid ..	400	102	48
10% sulphuric acid.. ..	145	28	2·1
10% sodium hydroxide ..	5·3	3·6	3·0

The cobalt-free tungsten carbide again stands out in respect of its immunity to attack by sulphuric acid. None of the alloys under test was attacked to any substantial extent by sodium hydroxide solution in the absence of air, even after immersion for five hours at 350° C. Articles moulded from fused boron carbide (B_4C) were also highly resistant to acid and alkali attack.

*From data published by W. Dawihl, *Chemische Fabrik*, April 20, 1940, pp. 133-6.

The Decomposition of Pearlite in Grey Cast Iron

IT has been known for some considerable time that grey cast iron undergoes a change in its structure on heating at high temperatures and that this change is due to the breakdown of the combined carbon. The phenomenon of "growth" has done much to promote the study of the conditions governing this decomposition. With the advent of heat-treatment of cast iron, an exact knowledge of the mechanism of pearlite decomposition has become more desirable.

An investigation, conducted with a view to determining some of the conditions governing the decomposition of pearlite in cast iron, is described in a paper by A. A. Timmins*. Two irons, of similar composition except for the silicon content, in the form of 1·2 in. diameter bars were studied. The analyses of the bars were as follows :—

	Iron *A*.	Iron *B*.
Total carbon	2·96%	3·09%
Combined carbon	0·70%	0·56%
Graphitic carbon	2·26%	2·53%
Silicon	1·85%	2·42%
Manganese	0·56%	0·73%
Sulphur	0·03%	0·03%
Phosphorus	0·18%	0·23%
Chromium	0·12%	0·13%

Sections of ½-in. thickness were cut from the bars and heated in a small electrically-heated tube furnace. The temperatures chosen were 700° C. and 900° C., so that the conditions governing the annealing could be studied at temperatures above and below the critical point of the iron used. The sections were placed in the furnace when at the desired temperature, and heated for ½ hr. or 2½ hr., after which they were withdrawn from the furnace and cooled in air. Other specimens were heated for the same periods at the same temperatures, but cooled at different rates, namely "slow cooling," approximately 3° C. per min., and "very slow cooling," approximately 1° C. per min. The critical points for the two irons were determined as follows :—

	Ac Point.	Ar Point.
Iron *A*	776° C.	721° C.
Iron *B*	792° C.	737° C.

Microscopic examination and combined-carbon determinations were conducted on the heat-treated samples in order to follow the changes which occurred. The work was carried out in the laboratories of the British Cast Iron Research Association.

The results of the investigation show that the annealing of grey cast iron involving the decomposition of pearlite may be readily accomplished at temperatures below the critical point, and that in such cases the rate of cooling after heating is of little importance. Annealing may be carried out at temperatures above the critical point, but when heating at constant temperature, pearlite will not be removed unless the initial combined carbon content is above that denoted by the equilibrium for the particular temperature and composition of iron used. The major factor in the removal of pearlite by a high-temperature anneal is the rate of cooling after the anneal, the slower the rate of cooling the greater being the amount of pearlite which is removed.

Confirmation is given which shows that the removal of pearlite in cast iron at constant temperature is a diffusion phenomenon. The rate of graphitisation at temperatures below the critical point is increased by an increase in temperature, and the most successful method of removing pearlite in grey cast iron is to heat at a temperature as near to the critical temperature Ac_1 as possible. Silicon does not appear to affect the rate of graphitisation at constant temperature. However, the facility with which high-silicon irons anneal may be accounted for by the fact that the as-cast combined carbon content is usually lower than for lower-silicon cast irons. The critical point is raised and the solubility of carbon decreased by an increase of silicon, which means that for a given temperature more pearlite may be removed than with an iron of lower silicon content.

Since the decomposition of pearlite becomes more rapid as the heating temperature is raised, the best method, particularly for high initial combined carbon contents, will be to start the anneal at some temperature above the critical point, and to reduce the temperature at some predetermined rate to a final temperature of annealing in the region of the critical point. After this treatment the castings may be cooled as quickly as possible consistent with other factors such as the possibility of warping or cracking. Data are given for the solubility of carbon in iron for temperatures up to 900° C. for three different silicon contents.

The results obtained have a great bearing on the commercial annealing of grey cast iron, the most important feature being that softening can be obtained most easily and more completely by annealing at temperatures near the critical point of the iron concerned. If higher temperatures are employed, very slow cooling is necessary in order to remove all the pearlite and obtain maximum softness.

In most cases, the softening of cast iron for the production of easily-machinable iron is carried out in a haphazard way and usually at temperatures above the critical point. Needless time and money are spent on long soaking periods at these temperatures, and, more often than not, the subsequent rate of cooling is too fast to accomplish the desired softening. The use of a soaking temperature near the critical point of the iron enables the annealing operation to be carried out more economically and removes the necessity for the slow-cooling period.

This research also has a bearing on the annealing of cast iron in the enamelling industry. An annealing treatment is often carried out on such iron in order to remove dirt and occluded gases, and the temperature required involves the decomposition of the combined carbon; unless the whole of the combined carbon is removed, it is often found that the resultant castings are warped.

Cases have been met with, particularly in continuous annealing plants, where a high-temperature anneal with a too-rapid cooling stage has been employed. The pearlite in the resulting castings was only partially removed, and considerable warping occurred when the castings were enamelled. A change in the heating temperature to 800° C. (2·8% silicon iron) resulted in the whole of the pearlite being removed. The warping during enamelling on such castings was thereby reduced considerably.

* Iron and Steel Inst. (Advance Copy) May, 1940

Small Furnaces for Heavy Service

CONTINUOUS development and research have evolved a range of heat-treatment for furnaces which combine accuracy of control, uniformity of heating, robust construction, and reliability of service. One of the most popular ranges of standard furnaces introduced by Birmingham Electric Furnaces, Ltd., is described in a brochure recently published by this firm. Known as the heavy service type of furnaces, they are available in convenient sizes developed as a result of actual experience of production requirements. The chief features of these furnaces are the heavy section nickel-chromium resistors, bent into sinuous form and mounted on patented metal hook supports, and the means taken to provide and maintain uniform heat distribution throughout the furnace. To secure this the elements are placed to heat the charge as uniformly as possible, and the heat-output of the elements in various parts is regulated to compensate for heat losses. To neutralise losses near the opening a heating element is incorporated in the door, regulated by a patented control system by which the proportion of heat input from the door element is increased during "soaking" periods, thus maintaining a uniform temperature throughout the heating cycle.

Copies of the brochure may be obtained from the firm at Erdington, Birmingham, 24.

CARBON STEEL

By William Ashcroft

Carbon steel holds its premier position largely because of the demand for low cost production, but refinements in manufacture and in processing have increased their scope in many directions; the many grades produced are more uniform in quality and therefore are more reliable than formerly.

STEEL, because of its combination of strength and workability, together with its relative cheapness, is the main engineering material, indispensable alike in peace and war. Variations of carbon content, or the inclusion of varying amounts of different elements in the composition of steel, provide a range of properties unsurpassed by any other material. From a tonnage point of view the industrial application of plain carbon steels far exceeds that of alloy steels; indeed, it is probable that the tonnage of plain carbon steel, subjected to heat-treatment during processing, is greater than the tonnage of all alloy steels put together. Thus, despite the development and progress in the application of a very wide range of alloy steels, the application of plain carbon steel continues to be a predominating feature in this and other steel-producing countries. These steels hold their premier position largely because of the demand for low-cost production, but it should be remembered that while considerable work has been, and still is being, devoted to the development of alloy steels, carbon steels have not been overlooked and refinements both in manufacturing and subsequent operations have increased the usefulness of these steels.

Theoretically, the carbon contents of steel may vary from a few hundredths to about 1·7%, but steel is not a pure alloy of carbon and iron, and other elements which are present in the composition have some influence on the carbon content, and in practice the upper limit is not clearly defined. With the exception of tool steels very few steels contain more than 1·0% of carbon, and those that contain less than 0·05% carbon are frequently spoken of as irons, since they are only slightly affected by heat-treatment. This relatively small difference in carbon content provides a comprehensive range of steels with varying properties, and the ability to make a full range of carbon steels can really be regarded as the first stage in the modern development of steel. Carbon, of course, has been associated with steel since ancient times, but until the discovery of the Bessemer process, which gave the world a really low-priced steel, the application of steel was on a relatively small scale and was confined largely to high-carbon steels produced by the crucible process. The first public announcement of the Bessemer process was made in 1856; thus, the use of steel in the service of mankind can be said to have been developed to its present huge tonnage in about ninety years.

Although the greater application of steel began with the discovery of cheaper methods of production, researches on steel were carried out before these discoveries were made. Faraday, for instance, devoted much time and energy to the investigation of steels and alloys during the period 1819 to 1824, the importance of which has only been appreciated in more recent years; but it is probable that the failure of other workers to develop the results of Faraday's work at that time on alloy steels was due, in a large measure, to lack of knowledge and the need for better methods of manufacturing ordinary carbon steel. It is not the purpose of this article to detail the gradual development in the production of carbon steel from those early days, but to direct attention to recent refinements in its manufacture and subsequent processing which enable carbon steel to meet the increasing demands made upon it.

Tapping an open-hearth furnace in the steelworks of the Ford Rouge plant.

It is true that in some respects more exacting engineering demands have limited the application of carbon steels; thus, for long life at high and low temperatures, equal strength and toughness with decreased weight, high fatigue values under severe service and high resistance to corrosion, alloy steels have become essential, but increased control in manufacture, resulting in a more uniform product, together with improvements in processing methods have increased the scope of carbon steels in many directions. The increased control in manufacture is due to intensive individual and, particularly, co-operative research which has been carried out during recent years.

Trend towards Improved Quality

Even in steel of a common grade the trend in manufacture during recent years has been towards improved quality, and this is being facilitated by the increased knowledge of the factors governing its manufacture. For those steels upon which much forging work is necessary, and which are required to pass very stringent tests, the design of furnace, the particular process of manufacture and its control are now carefully considered in the light of experience and research, to ensure, as far as is possible, that such steels will satisfy these tests after forging and heat-treatment. Whatever process of manufacture is adopted, scientific control of the various operations is now recognised as essential to success. Even in the application of the most advanced methods, however, high-quality steel manufacture depends upon the skill of the steel-maker. It is for this reason that accumulated experience, as well as research data, in such operations as making and melting the charge, finishing the bath, tapping the heat and teeming from the ladle, contributes to the production of quality steel.

Much of the carbon steel produced is used direct in the form of bars, sheet or sections, forgings and castings, but its application would be greatly curtailed if its properties were so limited. The improvement in the properties of this steel, however, by controlled heating and cooling, and the wide range of properties obtained by heat-treatment processes, make it indispensable in every branch of engineering.

Despite the amount of work devoted to alloy steels, it is interesting to note that no steel with any appreciable proportion of an alloying element has yet been discovered capable of taking quite the same hardness in a cutting

edge as carbon steel at ordinary temperatures of use. High-speed steels are, of course, exceptional, cutting tools of these materials being used at or near red heat. Toughness, however, is not a characteristic of these higher carbon steels, and for this reason small quantities of alloying elements may be added to such steels to promote this property. It is generally recognised that the advance in knowledge resulting from work on alloy steels has, in fact, reacted upon the technology of carbon steels, and has led to the discovery of the fact that properly treated carbon steels are comparable with some of the more expensive alloy steels in many applications.

Users of steel, who fabricate it into various forms, and metallurgists, who are constantly trying to improve the quality of steel products, exert pressure upon the steelmaker for higher quality steels at low cost, and refinements which have been effected have resulted in considerable improvement. The installation of modern plant, or the modernisation of existing plant, has contributed in some measure; but in addition to mechanical improvements and the greater use of labour-saving devices and equipment there is greater uniformity in the charge to the open-hearth furnace, which is generally employed, and the melter receives more assistance in determining the quality of the steel and in improving its uniformity. Furnace operations have been improved by instrumental control of such factors as control of air and gas, automatic reversal of furnace, and control of combustion. In recent years much attention has been given to slag control, and although considerable development in this direction is necessary before it becomes an established practice, many plants have adopted this means of control to improve the quality and uniformity of steel.

Controlling Factors

Many factors are involved in the practice of slag control, and it is not proposed to discuss them here, but it is generally recognised that the rate at which carbon is reduced is governed by the oxidation of the heat, and this is controlled by suitable conditioning of the slag. The manner in which the slag is controlled, however, varies with the type of steel being made; thus, for instance, a killed steel requires different treatment from a semi-killed or a rimmed steel. Samples of slag taken during the progress of a heat are becoming as important as samples of the metal in effecting control of the quality of steel being manufactured. Apart from the content of the slag, its fluidity is an important factor in assisting the removal of non-metallic matter from the heat and thus producing a cleaner metal. Much work has been devoted to the effects of non-metallic inclusions in steel in recent years, and it has been shown that these inclusions play an important part in determining the physical properties of the finished metal. The view is generally held that for high-quality steel it is essential that the non-metallic content should be as low as possible; it is not surprising, therefore, that attention directed to slag control is contributing to cleaner steel.

Another controlling factor to which considerable attention has been given is that of grain size. It is stated that the inherent nature of a controlled grain-size steel is that the size of grain under a given set of conditions can be forecast and assured. It has been shown that the principles involved in the production of controlled grain-size steel depend in some way upon the method adopted in deoxidising a heat, since it is generally agreed that the products of oxidation should be removed from the steel to the maximum possible extent before the steel solidifies in the form of an ingot. Thus it can be said that quality is inseparably associated with cleaner steel.

Apart from progress in manufacture, the increased control of tapping and pouring steel in modern practice has greatly facilitated cleanliness and soundness in the resulting ingot. In comparison with even 10 years ago, steel manufactured to-day for a particular application is both improved in its physical properties and more uniform in its characteristics. This applies to the low-carbon rimmed steels, produced as strip or sheet and in great demand for deep drawing and press work, as much as to the fully killed high-carbon steels, such as may be used for press dies, and embrace the complete range of carbon steels. The ability of the steelmaker has really advanced with the improved technique adopted by the users of steel and the more-exacting specifications with which it must comply. The greatly increased speed in the making of many steel products to-day would have been practically impossible 10 years ago with the carbon steels then available.

There can be no doubt that much work of a fundamental character carried out in recent years has improved the general quality of steel ingots. This has been concerned not only with the control of operations in steelmaking but also with a study of the reactions proceeding within the steel in the furnace, in the ladle, and in the mould, while the control of casting conditions and the study of the design of ingot moulds have also contributed. But the subsequent treatment of the ingot has also been improved in the continual desire to produce better steel of uniform quality. To-day there is much greater control of the roughing and finishing temperatures employed in hot rolling; furnaces are automatically heated to a temperature which will enable the rolling of the steel to be completed within the most suitable range for the structure desired. This is especially true in the reheating of slabs and billets, from which the finished products can be given the desired combination of ductility and strength.

Improved Heat-treatment

In addition to progress in manufacture which has been effected by closer control of steelmaking processes, refinements in heat-treatment methods and improved equipment have contributed to improvements in carbon steels. Processes that were at one time confined to the laboratory have become a part of normal production through the development of special equipment and control devices. Continuous and automatic methods of heat-treatment now perform various operations with a speed and accuracy that surpass the imagination of even 20 years ago and maintain a uniformity of quality which was impossible of attainment at that time. In heating and cooling, whether for softening or hardening the steel, the degree of accuracy achieved in normal practice and with modern equipment and appliances is such that a particular structure for a specific purpose can be obtained with remarkable regularity.

Finer Grading

With the closer control of steelmaking processes and the development of more accurate heat-treating methods the gradation of properties of carbon steels has become finer and finer, with the result that the user is confronted with a very wide range from which to make his choice. As is well known, steel gradually increases in strength and diminishes in ductility as the carbon content is increased. As a rule the carbon content required is laid down by a particular specification; thus, for hot-rolled strip and bars, cold-rolled strip for tin-plate, tubes, nails, rivets, etc., the carbon content of the steel is between 0·07 and 0·15%; for lap-welded seamless boiler tubes, 0·08 to 0·18%; boiler and ship plates, 0·13 to 0·18%; channels, angles, joists, tie-plates, etc., 0·15 to 0·20%; fishplates, 0·25 to 0·40%; rails, 0·50 to 0·90%; die-blocks, 0·55 to 0·65%; vehicle and general purpose springs, 0·85 to 1·05%.

Steels are manufactured to meet specifications necessary for forging applications; thus, for railway and general engineering forgings and for forgings which are subsequently case-hardened, for which a tensile strength of 24 to 30 tons per sq. in. is adequate, a 0·10 to 0·20% carbon steel is specified; for high-pressure reaction chambers, boiler drums, marine shafting, locomotive, gas-engine and marine crank axles, and general medium tensile engineering forgings, the carbon content is 0·22 to 0·26%. Other

(*Continued on page 100.*)

The Brittle Phase in High Chromium Steels—Part II.

By J. H. G. Monypenny, F.Inst.P.

This article is a continuation of that by the author published in the March issue on the hard, brittle and non-magnetic constituent found in certain high chromium steels. The work of further investigators on the structure of alloys is reviewed, and particular attention directed to the iron-chromium-manganese alloys. It is concluded that whatever the constitution of this phase, it possesses a complex structure the elucidation of which must await an exhaustive study.

POSSIBLY the earliest publication regarding the use of chromium-manganese steels as heat-resisting steels is the U.S. Patent[12] taken out by F. M. Becket in 1920. In this patent, steels containing 10–45% chromium and 2–25% manganese (together with up to 3% each carbon and silicon) were claimed as being machinable, responding readily to heat-treatment, resisting oxidation at high temperatures, and having a low magnetic permeability. Ten years later, Becket[13] published an account of the properties of low carbon steels containing about 18% chromium together with various amounts of manganese. He showed, *inter alia*, that such steels did not become completely austenitic even with the addition of 16% manganese; they contained some ferrite in equilibrium with the austenite. Subsequently a number of papers were published in Germany dealing with the constitution of chromium-manganese steels, and these were reviewed by the writer about two years ago in this journal.[14] The investigations on which these papers were based had for one of their objects the determination of the conditions leading to the production of the sigma phase. Further information on this subject has since been obtained by Burgess and Forgeng,[15] two of Becket's colleagues at the Union Carbide and Carbon Research Laboratories, Inc. They examined a number of low carbon alloys containing between 6% and 60% chromium and up to 50% manganese. Table VI gives analyses and also other properties which will be discussed later. In passing, it may be noted that none of their alloys with over 30% chromium contained more than 5½% manganese and that 14 of them contained 17% or 18% chromium, a feature which may possibly be related to the earlier investigations of Becket on alloys of this type.

Burgess and Forgeng examined the structure, hardness and magnetic properties of their alloys after quenching from 1,000° C., and also after furnace cooling from the same temperature. Unfortunately, the details they give regarding the latter treatment are rather vague. They say the alloys were held at 1,000° C. "for periods of up to 15 hours, followed by slow cooling," but they give no indication of the actual rate of cooling adopted. Their method of testing magnetic properties was only rough, and consisted in measuring the force necessary to separate the specimen and the poles of a small powerful magnet, this force being measured by the extension in inches of a light spring.

Structural conditions at 1,000° C. deduced from examination of samples water-quenched from that temperature, are shown by the continuous lines in Fig. 7. Alloys whose compositions lie above A B C consist of the α phase (ferrite), and below D E F of the γ phase (austenite); between the lines, alloys contain both these phases. It should be noted that the diagram—as the authors state—is intended to apply to alloys of low carbon content, about 0·1%, and not to carbonless alloys; with this in mind, it may be suggested that point A is at a rather low chromium content. The duplex ($\alpha + \gamma$) field in low carbon alloys, should surely extend beyond 16% chromium; indeed, the authors' own results indicate that this is the case, as they state that alloy No. 10 (17·0% Cr, 0·35% Mn, 0·05% C) had a duplex structure at 1,000° C.

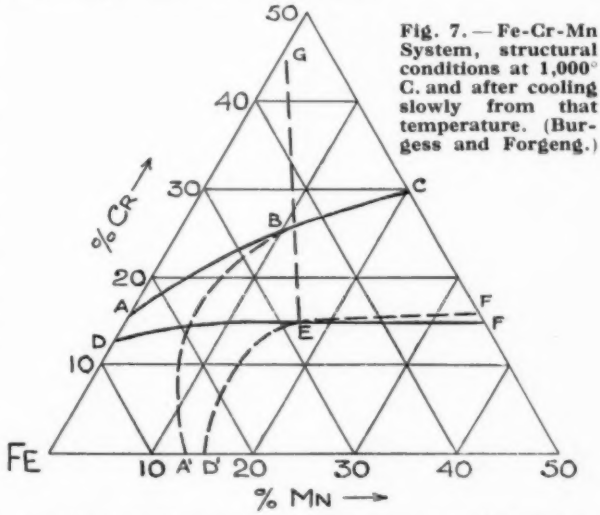


Fig. 7.—Fe-Cr-Mn System, structural conditions at 1,000° C. and after cooling slowly from that temperature. (Burgess and Forgeng.)

In thus dividing structural conditions at 1,000° C. into three zones, the authors are in agreement with Schmidt and Legat, whose structural diagram[16] was in essentials similar to that plotted in Fig. 7. In both investigations, it was found that the austenite field did not extend beyond about 15% chromium even with large additions of manganese, but the width of the duplex field increased as manganese content rose. The position of line A C agrees well with that in Schmidt and Legat's diagram.

The structure and properties of the alloys after slowly cooling from 1,000° C. presented several interesting features. In the first place, as would be expected, the austenite in alloys of low manganese content was unstable, decomposing during cooling into pearlite or one of the transition forms between that constituent and austenite. Hence, in the slowly cooled alloys, the alpha phase was found to the left of A'B, whilst alloys below and to the right of D'E F consisted of gamma iron. As before, alloys between these lines contained both phases. In addition, alloys to the right of E B G contained the sigma phase. There seems to have been some discrepancy between the results obtained on the one hand by X-ray analysis, and on the other hand by microscopic observation and magnetic tests (e.g., alloy 41, after furnace cooling is reported to be strongly magnetic, whereas according to X-ray analysis it consists entirely of the sigma phase), but the lines drawn in Fig. 7 correspond with those in the diagram of the original paper. According to the latter, the two alloys containing approximately 45% chromium, consisted entirely of the sigma phase; the

12 U.S. Patent 1,333,151. March 3, 1920.
13 "Chromium-Manganese Steels." American Iron and Steel Inst. May, 1930.
14 METALLURGIA, Nov., 1937, p. 7; Jany., 1938, p. 93.
15 "Constitution of Iron-Chromium-Manganese Alloys." American Inst. Min. and Met. Eng. *Trans. Iron and Steel Division.* 1938, p. 277.

16 See Fig. 1, p. 7, METALLURGIA, November, 1937.

other alloys lying in the area of G B C contained also appreciable amounts of the alpha phase. C B E F′ is the triple $\alpha + \gamma + \sigma$ field, and the narrow strip F E F′ the duplex $\gamma + \sigma$ field. The latter contains only one alloy (No. 9) and although the diagram in the original paper indicates that this alloy consisted solely of the gamma phase, the table of X-ray results states that it had a structure of $\gamma + \sigma$.

Fig. 8 represents the conclusions of Burgess and Forgeng as to structural conditions at 650° C. They state that this

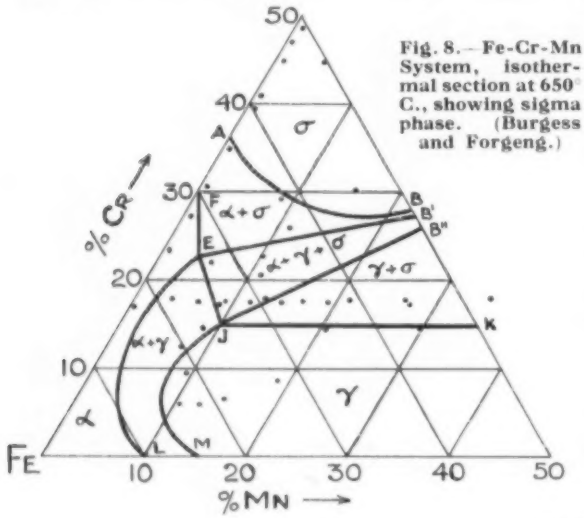


Fig. 8.—Fe-Cr-Mn System, isothermal section at 650° C., showing sigma phase. (Burgess and Forgeng.)

diagram "was deduced from microscopic examination of alloys annealed for very long periods of time at temperatures between 600° C. and 1,000° C. . . ." but they do not give any details at all of the actual results of these experiments, so that one can hardly comment critically on their findings. In the reproduction of their diagram in Fig. 8 dots have been inserted marking the compositions of the alloys which they examined; it will be obvious from the location of these dots that the positions of lines A B, E B′ and J B″ can be regarded only as tentative suggestions, at least as regards alloys containing more than about 10% manganese. This point will be referred to later when the work of Schafmeister and Ergang is being considered.

During the discussion on this paper at the meeting of the American Institute of Mining and Metallurgical Engineers, held in February, 1938, E. R. Jette asked why the boundary between the σ and $\alpha + \sigma$ fields (i.e., point A on Fig. 8) was placed as low as 36% chromium in the FeCr binary diagram, and mentioned that results of some experiments he had carried out indicated that this point should be nearer 45% than 36%. In their reply, Burgess and Forgeng stated that a 39% chromium alloy (presumably No. 36 in Table VI and containing actually 39·7%) produced 10% of the sigma constituent at 800° C. and rather more than 50% at 700° C. They continued, "We made the assumption that at some lower temperature sufficient holding time would have completely converted the alloy to the sigma phase." This would seem rather slender evidence on which to place the boundary of the sigma phase at 650° C. at as low a chromium content as 36%!

Burgess and Forgeng record a number of interesting observations regarding the microstructural appearance of

TABLE VI.

ALLOYS EXAMINED BY BURGESS AND FORGENG.

No.	Composition.				Structure at 1,000° C.	W.Q. 1,000° C.		F.C. 1,000° C.			
	C.	Si.	Mn.	Cr.		Brinell.	Relative Magnetism.	Micro-structure.	Brinell.	Relative Magnetism.	X-ray structure.
1	0·10	0·27	10·2	6·1	γ	418	11	α + γ	—	11	α + γ
2	0·10	0·25	12·1	6·0	γ	302	4	α + γ	—	4	—
3	0·05	0·41	14·5	6·6	γ	185	0	γ	—	0	γ
4	0·11	0·52	18·7	8·4	γ	163	0	γ	—	0	—
5	0·08	0·36	9·2	9·3	γ	345	12	—	—	—	—
6	0·15	0·15	7·2	12·1	γ	364	18	α + γ	—	18	α + γ
7	0·07	—	8·1	14·8	α + γ	—	17·5	α + γ	—	18	α + γ
8	0·12	0·55	20·5	14·6	—	170	0	γ	156	0	γ
9	0·12	0·42	29·8	14·7	α + γ	187	0	γ	—	0	γ + σ
10	0·05	—	0·35	17·0	α + γ	149	20	α	—	20	α
11	0·08	0·59	3·7	17·9	α + γ	187	20	α	—	20	—
12	0·06	0·32	6·5	17·5	—	—	—	—	—	—	—
13	0·11	0·24	8·4	17·2	α + γ	183	12	α + γ	269	18	—
14	0·07	0·33	8·9	17·8	—	—	8	—	—	—	α + γ
15	0·09	0·30	11·6	17·7	α + γ	187	4	—	—	—	α + γ
16	0·06	0·27	12·5	17·9	α + γ	—	4	—	—	—	α + γ
17	0·06	0·28	14·5	17·5	α + γ	163	5	α + γ	—	3·5	—
18	0·05	0·27	16·5	17·9	α + γ	—	1	α + γ + σ	—	0 +	—
19	0·05	0·23	19·1	17·5	α + γ	163	6	α + γ + σ	—	0 +	α + γ + σ
20	0·10	0·30	21·0	17·9	α + γ	174	—	—	—	—	—
21	0·06	0·30	26·5	17·9	α + γ	—	—	—	—	—	α + γ + σ
22	0·08	—	27·0	17·5	α + γ	332	0 +	α + γ + σ	—	0 +	—
23	0·12	0·31	35·2	18·5	α + γ	340	0 +	—	—	—	—
24	0·13	0·38	40·4	18·5	α + γ	418	0 +	—	—	—	—
25	0·12	0·36	49·9	18·5	α + γ	—	—	—	—	—	—
26	0·12	0·35	0·53	23·7	α	164	20	α	179	20	α
27	0·06	0·08	5·3	22·0	α + γ	163	20	—	—	—	—
28	0·09	0·35	11·0	20·4	α + γ	174	20	α + γ	196	9	α + γ
29	0·05	0·33	10·0	22·8	α + γ	159	20	α + γ	187	18	α + γ
30	0·10	0·37	0·63	27·3	α	183	20	α	217	20	α
31	0·05	0·31	11·1	26·0	α + γ	163	20	α + γ + σ	174	20	α + γ + σ
32	0·13	0·39	0·57	30·5	α	196	20	α	255	20	α
33	0·15	0·41	8·4	29·4	α	212	20	α	228	18	α
34	0·09	0·40	15·3	30·2	α	220	20	α + σ	495	0	α + σ
35	0·08	0·37	0·7	35·0	α	212	20	α	225	20	α
36	0·12	0·38	0·62	39·7	α	217	20	α	277	20	α
37	0·06	0·37	0·49	41·1	α	—	—	α	—	20	—
38	0·13	0·42	0·78	44·9	α	237	20	σ	532	0	α + σ
39	0·14	0·46	5·3	44·8	α	255	16	σ	532	0	α + σ
40	0·05	0·38	0·62	47·1	α	—	—	—	—	—	—
41	0·16	0·47	0·71	48·9	α	241	19	α + σ	351	17	σ
42	0·15	0·57	0·78	58·3	α	273	14	—	364	—	α
43	0·15	0·62	5·31	59·1	α	293	4·5	—	364	—	α

the sigma constituent and also the effect of manganese in accelerating the ferrite to sigma transformation. As regards the latter, they mention that whereas alloy No. 38 (44·9% Cr, 0·78% Mn) required seven hours at 700° C. for complete conversion from ferrite to sigma, alloy No. 39 (44·8% Cr, 5·3% Mn) only required an hour. In addition, manganese widened the temperature range in which the sigma phase is stable, as shown by the results in Table VII.

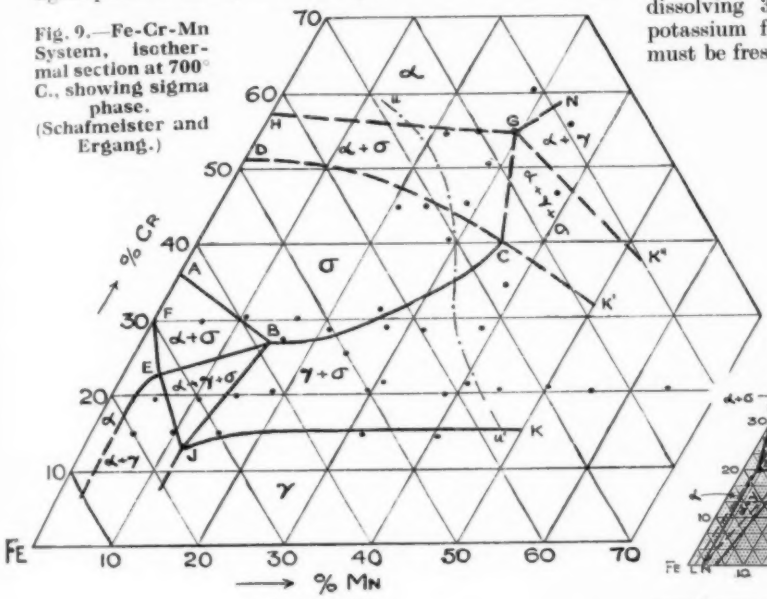


Fig. 9.—Fe-Cr-Mn System, isothermal section at 700° C., showing sigma phase. (Schafmeister and Ergang.)

TABLE VII.

EFFECT OF MANGANESE ON MAXIMUM TEMPERATURE AT WHICH THE SIGMA PHASE IS FORMED.

Alloy No.	Cr, %.	Mn, %.	Maximum Temperature at which Sigma Phase is formed. °C.
32	30·5	0·57	(*a*)
33	29·4	8·4	800
34	30·2	15·3	900
35	35·0	0·70	700
36	39·7	0·62	800
38	44·9	0·78	850
39	44·8	5·3	950 +
41	48·9	0·71	850 +

(*a*) None formed in finite time.

In connection with the temperature values given for alloys 36, 38, and 41, it may be recalled that Jette and Foote have published data showing that in pure alloys containing about equal amounts of iron and chromium the transformation alpha ⟶ sigma is reversible at a temperature between 775° and 800° C.* Unless, therefore, one assumes that the small amounts of manganese and silicon in Burgess and Forgeng's alloys have had a very pronounced effect, there would appear to be some discrepancy between the results obtained in the two investigations.

As regards microstructural characteristics, it will be recalled that Schafmeister and Ergang, when examining iron-chromium-nickel alloys, found considerable difficulty in distinguishing the alpha and sigma phases under the microscope in spite of the use of a number of different etching reagents; Burgess and Forgeng report two methods which they found satisfactory. In the first, the sample is etched lightly with a 10% solution of hydrochloric acid in water. With ordinary illumination an alloy converted into the sigma phase then appears very similar to the same alloy in the alpha condition except for the presence of numerous cracks. With polarised light, however, the sigma phase is decidedly anisotropic, and hence, when rotated between crossed nicols, the separate grains of this phase become alternately bright and dark. Photomicrographs of alloy 39, which had been held for two hours at 700° C., resulting in complete conversion to the sigma phase, show that the grain boundaries of the latter phase do not correspond with the boundaries of the alpha grains from which they were formed; the grain sizes of the two phases, however, were of the same order of magnitude. In the second method, the sample is etched with a modified Murakami reagent prepared by dissolving 30 grms. each of potassium hydroxide and potassium ferricyanide in 60 cc. of water; this reagent must be freshly prepared and is used boiling. This method would appear to be more suitable for alloys containing both constituents in massive form as the reagent colours them differently. The authors give as an example a photograph of alloy 33 after being held at 800° C. for 100 hours. This alloy then consisted mainly of ferrite, but with a network of the sigma phase; after etching, the latter was coloured light blue and the former yellow.

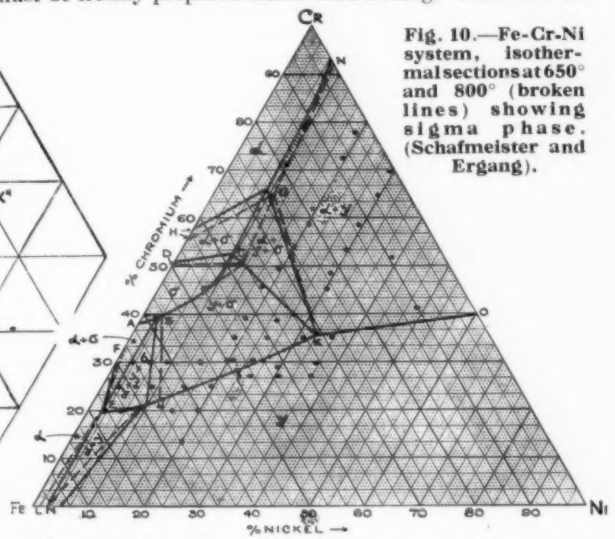


Fig. 10.—Fe-Cr-Ni system, isothermal sections at 650° and 800° (broken lines) showing sigma phase. (Schafmeister and Ergang).

With reference to the grain size of the sigma phase, Burgess and Forgeng note that this is larger the higher the temperature of conversion; they do not mention, however, whether the grain size of the pre-existing ferrite had any effect in this direction.

More detailed results of a systematic examination of iron-chromium-manganese alloys are given in a paper by Schafmeister and Ergang.[17] They re-examined very carefully the microstructures of the low carbon samples previously prepared and investigated by F. Brühl,[18] and also a further batch of 29 experimental alloys melted in a 3 kilog. high-frequency electric furnace. The latter alloys were heated for 30 mins. at 1,200° C. and then quenched in water; they were examined in that condition, and after annealing for 8, 50 or more hours at 650° C. and 750° C. the samples being air-cooled from their respective annealing temperatures. Brühl's samples had similarly been water quenched from 1,200° C. and then annealed for 8-hour periods at 700° and 800° C.; these annealed samples had been water quenched from their respective temperatures. In addition, selected samples were held for long periods at 700° C. and then air cooled or quenched in either water or oil. Besides microscopic examination, magnetic and hardness values and X-ray structure were also determined on many of the alloys. Tables VIII and IX give data regarding these tests, and also composition; in these tables W.Q., O.Q., and A.C. indicate water-quenched, oil-quenched, and air-cooled respectively.

From the results of all these tests, coupled with data taken from the paper by Burgess and Forgeng, Schafmeister and Ergang constructed the diagram shown in Fig. 9, as

* See Part I of this article. METALLURGIA, March, 1940, p. 144.

17 "The Brittle Sigma Phase in the Fe-Cr-Mn Constitutional Diagram. Schafmeister and Ergang: Technische Mitteilungen Krupp. *Forschungsberichte*. March, 1939.

18 *Archiv f.d. Eisenhüttenw.* X (1936-7), p. 243 *et seq.* See METALLURGIA, Nov., 1937, p. 7, and Jan., 1938, p. 93.

indicating the probable form of part of the isothermal section at 700° C. through the ternary FeCrMn diagram. At the higher chromium and manganese contents the phase boundaries are only approximate and are drawn in broken lines. The authors mention that, at these higher alloy contents, transformations appeared which were not explainable and which would have necessitated a closer investigation of the effect of structural changes in manganese on the ternary diagram and a working out of the as yet unknown Cr–Mn binary diagram.

The diagram in Fig. 9 is similar in construction—at least as regards the iron corner—to that obtained by the same authors for FeCrNi alloys, and reproduced in Fig. 10.* There is the same tunnel formation of the σ and $\gamma + \sigma$ fields bounded on each side by tunnel walls of the $\alpha + \sigma$ and $\alpha + \gamma + \sigma$ fields. The tunnel, however, extends very much more deeply into the ternary diagram than it does in the nickel-containing alloys. Whereas the sigma phase appears to be able to dissolve only about 10% nickel, the limiting value in the case of manganese is about 35%. Similarly, the duplex $\gamma + \sigma$ field ends at about 33% nickel, but its boundary has not been reached at 20% chromium and 64% manganese.

A comparison of Figs. 8 and 9 shows that line F E J occupies the same position in both diagrams except that, in Fig. 9, it extends to a rather lower chromium content to meet the curved end of J K. Schafmeister and Ergang state that some sigma phase was produced in alloy 15/10 after annealing for 8 hours at 800° C., though none was observed after similar period at 700° C., and they instance the somewhat lower saturation value in the former condition as being in agreement with this, although it might also proceed from a somewhat greater amount of austenite (changing to martensite during quenching) at the higher temperature. They place this alloy, therefore, on the boundary of the triple $\alpha + \gamma + \sigma$ field. The 15/15 alloy had a duplex structure of austenite and ferrite after quenching, but became practically non-magnetic after annealing, its microstructure showing clearly the break down of the ferrite. Incidentally, the sample of this steel, annealed at 700° C., was air-cooled from the annealing temperature, and this permitted the separation of the hexagonal ϵ-phase, of the FeMn system, in needle form in the austenite. Quenching would have prevented this separation.

Of the 20% chromium alloys, that containing 5% manganese consisted of ferrite and martensite after quenching, and no sigma phase was formed during annealing. The one containing 10% manganese consisted of $\alpha + \gamma + \sigma$ after annealing, the sigma phase existing as a dark border surrounding the ferrite grains. The lower hardness and higher saturation value of the sample annealed at 800° C., as compared with that at 700° C., is stated to indicate a partial re-formation of ferrite at the higher temperature. The alloys of this group with 15% manganese or more were all non-magnetic after annealing, and had a duplex structure of $\gamma + \sigma$. It may be noticed that there was no separation of the hexagonal ϵ-phase in the annealed samples of the 20/15 alloy, as these were quenched from the annealing temperature; had they been air-cooled, like the samples of the 15/15 alloy mentioned above, some separation of this phase might have been expected.

The 30% chromium alloy containing 5% manganese lies in the $\alpha + \sigma$ field, but, as Brühl pointed out, the breakdown of the ferrite takes place very sluggishly in this alloy. Increasing the manganese to 10% brings the composition on the boundary of the $\alpha + \sigma$ and the σ fields, and also increases very markedly the rate of formation of the sigma phase.

As mentioned earlier, there is an appreciable difference in the position of point B between Figs. 8 and 9. Probably the latter diagram is more nearly correct. One can at least say that all the alloys tested by Burgess and Forgeng which lie in the $\alpha + \sigma$ or $\alpha + \gamma + \sigma$ fields in their diagram are also correctly placed in Fig. 9.

The position of B C in Fig. 9 was determined mainly on microscopic observation. The full extent of the duplex $(\gamma + \sigma)$ field B C K′K J could not be traced as the sigma phase was still present in the alloy with the highest manganese content (64%) which was tested.

The magnetic properties of alloys containing 20% manganese and over were generally determined qualitatively only. Those lying to the left of line uu' were magnetic after quenching from 1,200° C., those to the right of this line, non-magnetic. All the alloys in the σ and $\gamma + \sigma$ fields were non-magnetic after annealing owing to the breakdown of the ferrite.

The $\alpha + \sigma$ and $\alpha + \gamma + \sigma$ fields, B H G C and C G K″ K‴ could only be determined approximately, and that chiefly by X-ray examination. Alloy 34/38, after annealing at 650° C., consisted mainly of sigma, a small amount of the γ phase being also identified in the microstructure though it was not found by X-ray analysis. Alloys 45/20, 45/24, and 40/29 lie entirely in the σ field, whereas alloy 45/29 showed definitely some α lines. These results give the approximate position of point C. The position of G also follows from the observed properties of alloys 55/22, 55/30, 55/35, and 60/29. X-ray analysis of alloys 46/38 and 20/64 showed the presence of strong sigma lines in the former alloy, but no indication of the alpha phase in the latter alloy; these two observations give some indication that the general direction of lines G K″ and C K′ is as shown in the diagram.

Schafmeister and Ergang mention that hardness and magnetic tests are not of much interest in this range of

TABLE VIII.

COMPOSITION AND PROPERTIES OF BRÜHLS ALLOYS.

No.	Composition.				W.Q. 1,200° C.				W.Q. 1,200° C., 8 hours, 700° C., W.Q.				W.Q. 1,200° C., 8 hours, 800° C., W.Q.			
	C.	Si.	Cr.	Mn.	Microstructure.	X-ray Analysis.	Inductance Gauss.	Brinell No.	Microstructure.	X-ray Analysis	Inductance Gauss.	Brinell No.	Microstructure.	Inductance Gauss.	Brinell No.	
15/5	0·03	—	15·0	5·0	α + Mart.	—	15,500	280	α + Mart.	—	16,000	255	α + Mart.	16,000	270	
15/10	0·05	0·18	14·8	9·7	$\alpha + \gamma$	—	6,000	210	α + Mart.	—	12,000	310	α+Mart.+(σ)	10,000	315	
15/15	0·07	0·31	15·0	15·1	$\alpha + \gamma$	$\alpha + \gamma$	5,000	185	(*a*) $\gamma+\sigma+\epsilon$	(*b*) $\gamma+\sigma$	500	255	$\gamma + \sigma$	Non-magnetic	222	
20/5	0·07	0·34	19·6	5·4	α + Mart.	—	13,400	190	α + Mart.	—	14,500	155	—	14,500	155	
20/10	0·15	0·48	19·7	10·4	$\alpha + \gamma$	—	7,900	200	$\alpha + \gamma + \sigma$	—	5,000	300	—	8,000	220	
20/15	0·15	0·54	19·9	14·6	$\alpha + \gamma$	—	7,900	190	$\gamma + \sigma$	(*b*) $\gamma+\sigma$	100	390	—	100	370	
28/16	0·10	—	27·6	16·2	α	—	9,300	260	σ	—	Non-magnetic	765	—	—	—	
30/5	0·05	0·48	29·9	5·7	α	—	11,700	190	α + (σ)	—	(*c*) 5,500	(*c*)425	—	—	—	
30/10	0·09	—	30·2	10·3	α	—	10,500	220	σ + (α)	—	1,100	670	—	3,900	685	
30/15	0·11	—	30·1	15·6	α	—	9,000	300	σ	(*d*) σ	(*d*) 400 Non-magnetic	650	σ	Non-magnetic	655	

(*a*) 8 hours 700° C., A.C. (*b*) 300 and 600 hours 700° C., O.Q. (*c*) 500 hours 700° C., W.Q. (*d*) 96 hours 700° C., W.Q.

* See the first part of this article. METALLURGIA, March, 1940, p. 145.

TABLE IX.

COMPOSITION AND PROPERTIES OF SCHAFMEISTER AND ERGANG'S ALLOYS.

No.	Composition.				W.Q., 1,200° C.			W.Q., 1,200° C., 8 hours, 650° C., A.C.			W.Q., 1,200° C., 8 hours, 750° C., A.C.		
	C.	Si.	Cr.	Mn.	Micro-structure.	X-ray Analysis.	Inductance.	Micro-structure.	X-ray Analysis.	Inductance.	Micro-structure.	X-ray Analysis.	Inductance.
15/32	0·04	—	14·8	31·6	γ	γ	Non-magnetic	γ	—	Non-magnetic	γ	γ	Non-magnetic
15/41	0·03	—	14·2	40·5	γ	γ	,,	γ	—	,,	γ	γ	,,
20/18	0·06	0·63	20·5	18·2	$\alpha + \gamma$	—	Magnetic	$\gamma + \sigma$	—	,,	$\gamma + \sigma$	—	,,
20/30	0·05	0·70	20·2	29·7	$\alpha + \gamma$	—	,,	$\gamma + \sigma$	—	,,	$\gamma + \sigma$	—	,,
20/31	0·04	—	21·5	30·8	$\alpha + \gamma$	$\alpha + \gamma$	,,	$\gamma + \sigma$	—	,,	$\gamma + \sigma$	σ	,,
20/38	0·06	0·96	19·9	38·6	$\alpha + \gamma$	—	Weakly magnetic.	$\gamma + \sigma$	σ	,,	$\gamma + \sigma$	σ	,,
20/40	0·05	0·93	21·3	40·3	$\alpha + \gamma$	—	,,	$\gamma + \sigma$	σ	,,	$\gamma + \sigma$	σ	,,
20/45	0·06	0·10	20·3	44·8	$\alpha + \gamma$	—	Non-magnetic	$\gamma + \sigma$	σ	,,	$\gamma + \sigma$	σ	,,
20/50	0·06	1·02	20·7	50·1	—	—	,,	—	σ	,,	—	σ	,,
20/55	0·06	1·12	20·1	55·5	—	—	,,	—	σ	,,	—	σ	,,
20/64	—	—	20·3	64·0	—	—	,,	—	—	,,	—	σ	,,
25/25	0·07	0·66	25·4	24·5	$\alpha + \gamma$	—	8,500 gauss	$\gamma + \sigma$	—	<500 gauss	$\gamma + \sigma$	—	<500 gauss
28/21	0·06	0·63	28·7	21·0	α	—	Magnetic	σ	—	Non-magnetic	σ	—	Non-magnetic
28/28	0·03	—	28·9	27·6	$\alpha + (\gamma)$	α	,,	$\sigma + (\gamma)$	—	,,	$\sigma + (\gamma)$	σ	,,
28/32	0·06	—	28·3	32·0	$\alpha + (\gamma)$	α	,,	$\gamma + \sigma$	—	,,	$\gamma + \sigma$	σ	,,
28/38	0·06	1·09	28·4	38·4	$\alpha + \gamma$	—	,,	$\gamma + \sigma$	σ	,,	$\gamma + \sigma$	σ	,,
31/26	0·05	—	31·2	25·5	α	α	5,400 gauss	σ	—	,,	σ	σ	,,
34/38	0·05	1·30	34·1	38·4	$\alpha + (\gamma)$	—	Non-magnetic	$\sigma + (\gamma)$	σ	,,	$\sigma + (\gamma)$	σ	,,
40/29	—	—	40·2	28·9	α	α	Magnetic	σ	(a) σ	,,	σ	(b) σ	,,
45/20	—	0·54	44·8	20·4	α	α	,,	σ	(a) $\sigma + (\alpha)$	,,	—	σ	,,
45/24	—	0·73	45·0	24·0	α	α	,,	—	(a) $\sigma + (\alpha)$	,,	—	σ	,,
45/29	—	—	45·2	28·6	α	α	Non-magnetic	—	$\sigma + \alpha$	,,	—	$\sigma + \alpha$	,,
46/38	—	—	46·1	38·2	α	α	,,	—	—	,,	—	$\alpha + (\sigma)$	,,
50/28	—	—	50·5	28·5	α	α	,,	—	$\alpha + (\sigma)$	,,	—	$\alpha + \sigma$	,,
55/22	—	0·75	54·4	21·7	α	α	,,	—	α	,,	—	$\alpha + (\sigma)$	,,
55/25	—	0·77	54·6	25·4	α	α	,,	—	α	,,	—	$\alpha + (?)$	,,
55/30	—	—	54·6	29·6	α	α	,,	—	$\alpha + (\sigma)$	,,	—	$\alpha + (\sigma)$	,,
55/35	—	—	55·8	35·3	α	α	,,	—	$\alpha + (\gamma)$	,,	—	$\alpha + (\gamma)$	,,
60/29	—	—	60·1	28·9	α	α	,,	—	α	,,	α	$\alpha + (?)$	,,

(a) 50 hours, 650° C., A.C. (b) 50 hours, 750° C., A.C.

composition, because, as mentioned earlier, the alloys are already non-magnetic when quenched and in addition they are extremely brittle, so that a reliable hardness value is not possible. Metallographic examination was also made difficult because the alloys absorbed nitrogen during melting, nitride needles being present in the structure. Analysis of some of the alloys gave the following values :—

Alloy	45/20	.. ..	0·14% nitrogen.
,,	45/24	.. ..	0·19% ,,
,,	54/30	.. ..	0·42% ,,
,,	60/29	.. ..	0·58% ,,

The nitrogen content thus rose markedly with that of chromium, a result which might be expected. In view of this contamination and its possible effect on structural conditions, the phase boundaries in these high chromium and manganese regions are drawn in broken lines only. There seems no purpose, however, in determining their positions more accurately because, as Schafmeister and Ergang remark, alloys in these ranges of composition are of no particular interest from a technical point of view owing to their great brittleness.

Practical Implications

The results which have been described as to the occurrence of the sigma phase in high chromium-nickel or chromium-manganese alloys of iron are somewhat startling in their implications regarding the technical use of these alloys. There seems no doubt that the sigma constituent is very hard and extremely brittle ; Riedrich, for example, during a discussion at Düsseldorf of papers by Brühl and by Schmidt and Legat,[18] stated that alloys consisting mainly of it were so brittle as to break like glass with the least bending. It is obvious, therefore, that all alloys which are liable to change more or less completely into the sigma phase when heated at a dull red heat should be regarded as quite unsuitable for purposes—e.g., heat resistance—in which such heating may occur. Whether they would be suitable for other purposes, which would not involve treating the steel in this way during use, would depend on whether the production of the sigma phase was likely to have a detrimental effect on hot-working operations incidental to the fabrication of the steel. As an extreme case, one may cite the experience of Brühl with those of his alloys which contained 30% chromium and 15% manganese. The production of the sigma phase occurred so rapidly in these steels that they could only be forged successfully by never allowing the temperature of the ingot, or the forging produced from it, to fall below 900° C. until forging was complete. The forging was then quenched out in water. If the sigma phase was allowed to form—e.g., by allowing the ingots to cool down—the latter broke into pieces on reheating. There would be less danger with alloys in which the $\alpha \longrightarrow \sigma$ change took place more sluggishly—e.g., in relatively pure iron-chromium alloys—but even a partial formation of the sigma phase would have a noticeable effect on ductility.

The ranges of composition of alloys which are liable to change bodily to the sigma phase are indicated approximately by the lines A B C D in Figs. 9 and 10. In both these diagrams, point A is taken from the results given by Burgess and Forgeng (Fig. 8), and attention has already been drawn to the slender evidence on which it is based and the possibility that it should be placed at an appreciably higher chromium content. It seems unlikely, however, that these FeCrNi and FeCrMn alloys will have any practical interest. If it were essential to use an alloy with as high a chromium content as 40 or 45%—e.g., for heat-resisting purposes—one would either convert it into a reasonably stable alloy by adding 35% or more of nickel, or else, if for some reason a ferritic alloy were desired, use a plain iron-chromium alloy which forms the sigma phase more sluggishly than the more complex ferritic alloys.

From a practical aspect, the most important parts of Figs. 9 and 10 are the double and triple fields which border the sigma field towards the iron corner of the diagram and, in particular, the actual position of line F E J K in the reasonably pure alloys and the effect on this position of additions of other metals commonly added to corrosion resisting or heat-resisting steels, especially those which are strongly ferrite-forming—e.g., aluminium, silicon, molyb-

denum, titanium, tungsten. The importance of the action of these metals follows from the fact, which has emerged from all the investigations regarding the sigma phase, that this phase is formed exclusively, or practically so, from the α-iron solid solution. Schafmeister and Ergang certainly mention an instance, seemingly exceptional, of its formation from the austenite in quenched nickel-containing alloys whose compositions lie in the $\gamma + \sigma$ field near the line J K. Elsewhere, however, they point out that the duplex $\alpha + \gamma$ field, which stretches at high temperatures across the ternary FeCrNi diagram, widens markedly as the temperature falls. It seems probable, therefore, that in this apparently exceptional case the quenched austenite from which the sigma phase formed was supersaturated and that at lower temperatures than that from which the alloy was quenched (1,200°) some ferrite would also be present.

It follows from this that alloys which normally consist entirely of austenite are not likely to suffer from the effects of sigma phase precipitation. On the other hand, alloys consisting of ferrite or having a duplex structure of ferrite and austenite, and whose compositions lie above or near to F E J K in Figs. 9 and 10, should be examined carefully as regards their structural stability if they are intended for use under conditions involving prolonged heating at medium temperatures.

As regards ferritic alloys, the practical implications of Figs. 9 and 10 seem fairly clear. Bain and Griffiths stated in their original paper[19] that in ferritic alloys, which were not of high enough chromium content to transform bodily into the sigma phase, the latter could form, during prolonged annealing, as a network round the ferrite grains which remained. Ferrite of high chromium content is not by any means a tough material, and hence one may expect that the formation of even a thin sigma network would have a serious embrittling effect. Bain and Griffiths mentioned that this could occur with chromium contents as low as about 30%—a figure which agrees with point F in Figs. 9 and 10—and these two diagrams show that this minimum content is lowered appreciably by the addition of nickel and manganese. One may conclude, therefore, that when ferritic alloys containing 25 or 30% chromium are desired for heat-resisting purposes, their contents of nickel and manganese should preferably be kept reasonably low.

Probably the most interesting application of the results summarised in Figs. 9 and 10 is in connection with steels having a duplex structure of austenite and ferrite, the austenite being the predominating constituent. Considering first low carbon iron-chromium-nickel alloys to which no other metal has been added, it will be seen from Fig. 10 that all such alloys with a duplex structure and containing more than about 20% chromium are liable to form smaller or larger amounts of the sigma phase on prolonged heating at a red heat, and hence to undergo embrittlement in greater or less degree. To avoid this, an increase in nickel content appears desirable, and if one accepts line J K as being reasonably accurate in representing the boundary between the $\gamma + \sigma$ and γ fields, it is evident that 20% chromium requires a minimum of 10% nickel and that each additional 1% chromium requires a further 2% of nickel to keep the composition out of the $\gamma + \sigma$ field. On this basis the 25% chromium 12% nickel alloy, which seems to have obtained considerable favour as a heat-resisting steel in the United States, would appear to be a less stable and, therefore, less satisfactory composition than the 25% chromium, 20% nickel alloy which is generally used in this country.

Duplex alloys in commercial use, however, generally contain appreciable amounts of other ferrite-forming metals—e.g., silicon, molybdenum, tungsten, titanium, aluminium—and the question arises as to whether these metals can replace chromium in the sigma phase and hence lead to the production of this phase at lower chromium contents. Silicon appears to have been studied more than the others, and may perhaps be taken as indicating the possible trend of other ferrite-forming alloys. The FeCrSi system, or rather the iron corner of it, has been investigated by Anderson and Jette,[20] using X-ray analysis. As might be expected, the system is complex owing to the formation of a number of silicides, but definite evidence was obtained that silicon speeds up considerably the $\alpha \longrightarrow \sigma$ change and also increases the temperature and composition ranges in which the sigma phase is stable. Fig. 11 indicates structural conditions at 600°, 800°, and 1,000° C. at the iron corner of the diagram, and shows clearly the effect of the silicon in thus extending the ranges of stability. Schafmeister and Ergang quote an example indicating that silicon has a similar action in more complex alloys; they mention that whereas an alloy containing 0·07% C, 0·37% Si, 0·51% Mn, 24·8% Cr, and 19·5% Ni showed no evidence of the sigma phase after annealing for 1,000 hours at 800° C., a very marked separation of this phase was observed, after a similar annealing, in an alloy containing 0·06% C, 2·94% Si, 0·58% Mn, 25·2% Cr, and 20·2% Ni.

That embrittlement does occur in some of the duplex alloys used commercially as heat-resisting steels is now common knowledge. An example of such embrittlement was given by the writer in a previous article,[21] and is quoted again in Table X as an illustration of what may occur in practice.

TABLE X.

EMBRITTLEMENT OF HEAT-RESISTING STEEL BY HEATING AT 850°–875° C.

C.	Si.	Cr.	Ni.	W.
0·35	0·90	22·2	8·6	2·6

Time at 850°–875° C.	Impact value after cooling.		
Nil	55	60	55 ft.-lbs.
8 hours	28	27	25 ft.-lbs.
24 hours	10	10	11 ft.-lbs.

Embrittlement has also been found in markedly duplex steels of similar chromium and nickel contents, but containing 2 or 3% of either silicon or molybdenum instead of tungsten. It is obvious, therefore, that the use of such duplex steels may be fraught with danger.

There is a further aspect of the matter, however, which also merits consideration. The chromium and nickel contents of the steels mentioned above bring the latter above the line E J K in Fig. 10—i.e., the steels would have been liable to undergo embrittlement in the absence of the tungsten, molybdenum or silicon they contained, although the presence of these metals may have increased the degree of embrittlement by making the steels more strongly ferritic. If, however, these metals had been added to an austenitic steel of lower chromium content, one not liable to undergo sigma formation, and had thereby produced a duplex structure of austenite and ferrite, would the ferrite thus formed be liable to change to the sigma phase on prolonged annealing? There is evidence that this may occur and to an extent which may have serious consequences. For example, an "18/8" steel to which 3½% molybdenum had been added, producing marked duplexity, was found to have embrittled badly after being held at 850° C. for 31 days, although a plain "18/8" steel heated in the same way retained practically its full toughness. It is obvious, therefore, that the question of the possible embrittlement of high chromium heat-resisting steels which are mainly austenitic, but contain also a proportion of ferrite in their structure, is one which merits careful investigation. Such steels are normally very tough, and hence an appreciable drop in impact value can occur and still leave them in a satisfactory condition for service—it is also by no means certain that completely austenitic steels which do not form the sigma phase, retain their toughness indefinitely when held for a prolonged period at a dull red heat,—but when an initial impact value of 60 or 80 ft.-lbs. can be reduced to less than 10 in a relatively short time, the matter is obviously on a different footing.

19 "An Introduction to the Iron-Nickel-Chromium Alloys," *Trans. American Inst. Min. and Met. Eng.* 1927.

20 "X-ray Investigation of the Iron-Chromium-Silicon Phase Diagram." A. G. H. Andersen and E. R. Jette. *Trans. A.S.M.*, XXIV (1936), p. 375.

21 "Modern Developments in Stainless Steels." *Metal Treatment*, Spring Number 1936, p. 24.

Precautions would appear to be still more necessary with steels in which nickel is replaced wholly or mainly by manganese. All investigators agree that manganese speeds up considerably the rate of sigma formation while Fig. 9 shows how very great is the range of composition of FeCrMn alloys which are liable to produce this phase. The safest plan would be to limit alloys used for heat-resisting purposes to those containing not more than 15% chromium and with sufficient manganese to render them stably austenitic.

The precise effect of carbon content seems to be somewhat in doubt. It undoubtedly acts as an austenite former, and its addition may therefore convert a mildly duplex steel into one completely austenitic when properly heat-treated. At first sight this would appear to be a means of reducing the extent of the sigma field and thus extending the range of composition of " safe " alloys. When these higher carbon steels are heated at medium temperatures, however, they precipitate carbide—presumably as a chromium carbide—and the alteration in composition of the ground mass so produced may cause the latter to revert from a completely austenitic state to one containing a proportion of ferrite with the possibility that the latter will change, partly or wholly, to the sigma phase. Schafmeister and Ergang give an illustration of the lack of beneficial effect of a carbon addition. Raising the carbon content from 0·06% to 0·32% of steel containing 25% Cr, 20% Ni, and about 2·5% Si—as mentioned earlier, the silicon content of the low carbon steel brings the latter into the $\gamma + \sigma$ field—neither reduced the amount of sigma precipitation nor lessened the embrittlement produced by annealing for 1,000 hours at 800° C.

The upper temperature limit of stability of the sigma phase has not been accurately determined, but it is obvious that it varies considerably with composition. It is apparently lowest in the pure FeCr alloys—tests by Jette and Foote mentioned in the first part of this article show that in such alloys the change is reversible at some temperature between 775° and 800° C. and is raised appreciably by nickel, manganese and silicon. This is obviously a matter of importance in connection with the industrial use of the steels for heat-resisting purposes ; it should also be kept in mind when investigating the stability of steels to be used in this way. Other things being equal, the speed of sigma formation increases with increase in temperature within the range of stability of the phase. It is a convenience, therefore, to test alloys at as high a temperature as possible. Care should be taken not to use too high a temperature when comparing a series of alloys, otherwise it may be above the stability range of the sigma phase in individual alloys and hence lead to erroneous conclusions.

Of equal importance, however, is the question of the lowest temperatures at which the sigma phase can be produced in any reasonable time. Most published data regarding the formation of this phase refer either to prolonged heating at temperatures between about 600° and 900° C., or to slow cooling from higher temperatures, and they indicate that, other things being equal, the rate of formation decreases as the temperature falls. There is evidence to show that the sigma phase is still produced, albeit more slowly, at temperatures well below 600° C. ; in some steels it can be formed at least as low as 450° C., a temperature reached, for example, in several chemical engineering processes and by superheated steam in modern power plant. This fact raises questions of considerable importance. Some of the special " 18/8 " steels which are used, or have been proposed for use, for these purposes have markedly duplex structures of austenite and ferrite. In some instance the production of this structure has been regarded merely as a secondary effect of the addition of appreciably amounts of some ferrite-forming alloy required for enhanced corrosion resistance, but in some steels at least the duplexity is regarded as an important, almost essential, feature on account of the higher yield-point value thereby obtained. This has been the case, for example, in some " special " steels put forward for use as turbine blading, particularly for that exposed to highly superheated steam. In modern power plant, such blading may work continuously at temperatures of 450° C. or over, and the possibility arises that these duplex steels may develop the sigma phase during use. One of these special steels—a complex alloy of the 18% chromium 8% nickel type, but containing also aluminium and titanium, both strong ferrite-forming metals—was recently tested by the author, and its Izod impact value was found to fall from about 50 ft.-lbs. to less than 10 ft.-lbs. on heating for 24 hours at 450° C. With more prolonged heating at this temperature the value decreased still further. Incidentally, the fairly rapid rate of embrittlement at 450° C. suggests that the steel in question would also embrittle at appreciably lower temperatures in periods of time well within the life of a modern turbine. It would seem dangerous to use such steels for turbine blading under temperature conditions which cause so marked an embrittlement.

The importance of the subject of sigma formation and the need for further investigation regarding the degree and rate of embrittlement as affected by composition and temperature need hardly be emphasized. It does not by any means necessarily follow that all steels which are subject to sigma precipitation, even in slight degree, are thereby unsuited for heat-resisting purposes—it is very probable that many whose compositions lie only just within the range of stability of the sigma phase will give perfectly satisfactory service under many industrial conditions—but it seems obvious that the use of steels which are liable to become very brittle in service should be avoided, and particularly so if the failure of a part so embrittled would have disastrous consequences. It may also be suggested that the use of doubtful steels having a duplex structure of austenite and ferrite is not advisable, especially if a remedy can be found, as, for example, by raising the nickel content so as to remove the duplexity. The added nickel may increase the cost of the steel somewhat, but surely that is preferable to the use of a cheaper material whose failure in service may cause considerable damage.

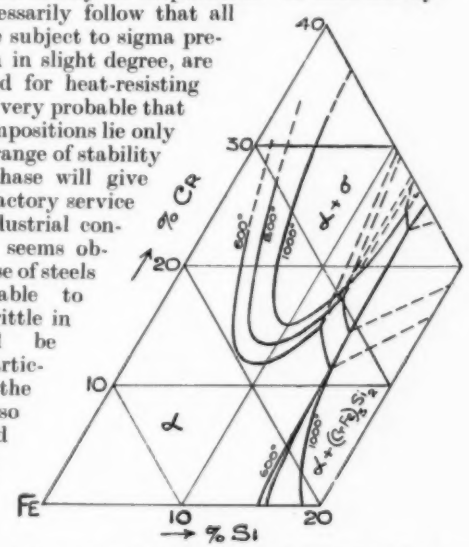


Fig. 11—Fe-Cr-Si System, structural conditions of iron rich alloys. (Andersen and Jette.)

The actual constitution of the sigma phase is still in doubt. The German investigators consider that it is based on the compound FeCr, and, as mentioned in the first part of this article, Wever and Jellinghaus have identified a phase in the iron-vanadium system which gives a similar X-ray pattern ; as they consider this phase to be the compound FeV, they regard the similarity in X-ray pattern as evidence that the sigma phase is the compound FeCr. If it is indeed this compound, the latter must have a remarkable capacity for allowing the substitution of iron and/or chromium atoms by atoms of nickel, manganese, silicon, and probably other metals without appreciable change in properties or in the positions of the lines in the spectra given by X-ray analysis. Burgess and Forgeng suggest that the sigma phase is " the result of an allotropic transformation of a highly saturated ferrite, other elements as well as chromium contributing to this saturated condition." Whatever the constitution of the phase, it apparently possesses a complex structure, and the elucidation of this must await an exhaustive study of the results obtained by X-ray analysis of alloys, both simple and complex, in which this remarkable phase is formed.

Phosphorus in Molybdenum Steels

The results of an investigation, carried out to determine the effect of phosphorus additions to the 5% chromium, 0·5% molybdenum steels, are given.

THE use of phosphorus as an alloying element is common in several of the commercial high-yield strength, low alloy steels, such as the chrome-molybdenum steels. Previous work having shown that phosphorus increases the high temperature strength of the chrome-molybdenum steels containing 1% chromium, 0·2% molybdenum; 1% chromium, 0·5% molybdenum; and 2·4% chromium, 0·2% molybdenum, an investigation was carried out recently by H. D. Newell and Z. E. Olzak* to determine the effect of phosphorus additions to the 5% chromium, 0·5% molybdenum steels. This research was made to ascertain what advantages or disadvantages such an addition would show in view of the services to which this type of steel is put in oil-refinery piping and still tubing, and for steam superheater tubes.

A series of steels having compositions as shown in Table I were cast from high-frequency furnace melts, forged at 1,150° to 1,175° C., and annealed at 860° C. for 1 hour, cooled at the rate of 11° C. per hour to 700° C., then cooled in the furnace.

TABLE I.

	1.	2.	3.	4.	5.	6.
	%	%	%	%	%	%
Carbon	0·098	0·104	0·108	0·092	0·092	0·12
Manganese	0·36	0·42	0·37	0·38	0·35	0·45
Silicon	0·356	0·334	0·28	0·40	0·30	0·418
Chromium	5·07	4·99	4·88	5·01	4·79	5·25
Molybdenum...	0·58	0·54	0·54	0·51	0·48	0·58
Phosphorus ...	0·02	0·116	0·094	0·202	0·46	1·00

Discs, ¾ in. in thickness, cut from the top of each ingot, machined, polished, and etched in hot 1 : 1 hydrochloric acid, showed segregation and pipe to increase gradually as the phosphorus increased, the pipe being especially evident in the ingot containing the high phosphorus content, a condition supposed to be due to the strongly deoxidising effect of phosphorus.

The proportional limit, yield-point, and ultimate breaking stress determined at room temperature showed a marked increase up to and including 0·46% of phosphorus. Above 0·46% phosphorus, the proportional limit and yield-point showed a drop, while the ultimate breaking stress remained constant. There was a slight decline in ductility starting with the 0·202% phosphorus steel, and this decline increased correspondingly to 1·0% phosphorus when a brittle fracture with very little elongation or reduction of area was obtained. The Brinell hardness increased from 124 with 0.020% phosphorus to 189 with 1·0% phosphorus.

The increased strength which is attributed to alloying with phosphorus also held at elevated temperatures. Short-time high-temperature tests were made on each of the steels, and their properties determined through the range 450° to 705° C. With the exception of the steel having the lowest phosphorus content (0·020%) all the steels show the yield-point to be higher at 450° C. than at room temperature. Charply impact tests made on standard notched specimens showed good resistance to impact on steels containing up to 0·202% phosphorus (Table II).

A slight decline in impact resistance with increasing phosphorus up to 0·202% was obtained, but this decline was not serious until the percentage of phosphorus was raised above 0·2%. At 0·46 and above the resistance to impact was practically zero, and appeared to indicate that the limit for alloying phosphorus with this type of steel would be about 0·25% phosphorus. Steel with phosphorus in excess of this amount would be of no use under service conditions, where material is intermittently used at elevated temperatures and is liable to be subjected to shock when temperatures are reduced.

TABLE II.

Steel.	Phosphorus.	Average Impact, Ft.-Lb.
1	0·020	49
2	0·116	41
3	0·094	37
4	0·202	35
5	0·460	2
6	1·000	2

Hardness tests made on air-cooled and water-cooled specimens at temperatures from 705° to 1,260° C. showed the hardness at temperatures up to 815° to increase with increasing phosphorus content. At temperatures over 815° C. results were irregular, but tended to show a slight decrease with increase in the phosphorus content. Polished samples from each of the steels exposed to the weather for 1,200 hours showed that with over 0·20% of phosphorus a better resistance to corrosion was obtained. Weld hardening tests were made on each of the steels in which a bar of the material was annealed, and a single bead of weld metal laid on by arc welding. In Table III the Rockwell hardness and the Brinell hardness equivalent of the weld metal and the heat-affectedr egions of the material in the "as welded" condition are given.

TABLE III.

Steel.	Weld Metal. Rockwell.	Weld Metal. Brinell.	Weld Affected Zone. Rockwell.	Weld Affected Zone. Brinell.
1	B–100	242	C–32	396
2	B– 96	216	C–35	322
3	B– 97	228	C–36	331
4	B– 98	222	C–37	340
5	B– 95	210	C–32	296
6	B– 98	228	C–34	313

From these tests it does not appear that phosphorus in any amount up to 1% reduces weld hardening to below that of a low phosphorus steel containing the same carbon content.

Micro-examination of all the steels in their annealed condition showed little difference in the microstructure of the lower phosphorus materials. The greatest change in structure was evident in the 0·46% and 1·0% phosphorus steels, which tended to have a larger grain size, and this is reflected in the tensile and impact tests. There was evidence of more carbon out of solution in the 1·0% phosphorus steel, which might partially explain the drop in the yield-point of this steel. The two higher phosphorus steels also contained free ferrite.

In general, the addition of phosphorus up to at least 0·20% to a 0·1% carbon, 5·0% chromium, 0·5% molybdenum raises both at room temperature and at elevated temperatures, the yield-point and ultimate breaking stress with little loss in ductility. Within that range of phosphorus satisfactory toughness and resistance to impact is retained, and satisfactory hardness is obtained both at low and elevated temperatures. The phosphorus does not materially decrease the weld-hardening of the steel. From a practical point of view, such an addition of phosphorus to chrome-molybdenum steels of the specified composition enhances the high-temperature properties at lower cost than by increasing the content of the alloying elements, and renders such steels suitable for constructional purposes.

*Metals and Alloys, 1940, Vol. II, No. 4, pp. 108-111.

Testing of Cutting Efficiency of Tools

By A. J. Schroeder, D.Sc.(Eng.)

The best guarantee of the service and cutting efficiency of high-speed tool steels is to make comparative tests on materials supplied for the purpose. Short, forceful or improvised experiments do not provide a reliable basis for comparison, but details of comparative turning tests are given which are claimed to determine cutting efficiency. Certain rules are given which must be followed when carrying out the tests.

TO determine the efficiency of steels, practical trials are often made of the working capacity of tools. There then arises the question of comparative tests, the quality and precision of which depend on the important factor as to whether the conditions under which the tests take place are uniform for all the tools tested, and whether the experiments are carried out under conditions that correspond as nearly as possible with the use of the tools in practice. It is often very difficult in the workshop to achieve either identical conditions for trial, or, for the obtaining of reliable average values, to test enough tools, particularly if a fairly large number of tools is to be tested. Moreover, special experience is necessary, as the result of these experiments often depends on seemingly insignificant details. Short, forceful experiments mostly lead to chance results, because abnormal stress brings to light properties of the material which are not called into use when the tools are employed for their proper purpose in the workshops.

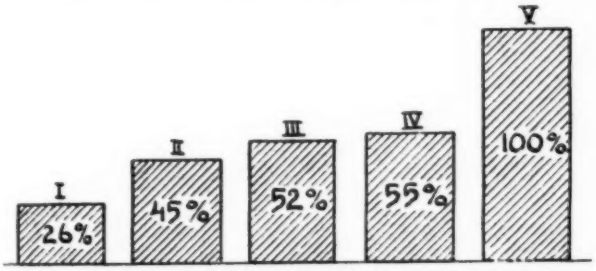


Fig. 1.—Comparative efficiency of high-speed tool steels of different origin and composition.

I—Cr-W-V-Special Steel with W = 23·5%, V = 1·1%
II—Cr-W-V-Special Steel with W = 22·0%, V = 2·0%
III—Cr-W-V-Special Steel with W = 17·8%, V = 2·6%
IV—Cr-W-V-Special Steel with W = 17·8%, V = 1·47%
V—Cr-W-V-Co-Special Steel with Co = 5·0%

Conditions of experiment:
Workpiece: Shaft of Siemens-Martin steel with about 65 ton/sq. in. tensile strength.
Cutting speed: 50 ft./min.
Depth of cut: 0·2 in.
Feed per revolution: 0·06 in.
Working: Dry.

Improvised experiments also do not generally yield an exact basis for comparison, as to efficiency and economy, of the steel so far used and the steel used for demonstration, because in such cases, for example, tools that have not been hardened quite properly are frequently compared with similar tools that are faultlessly hardened, and thus the increased efficiency of the latter may actually be due to the better hardening, and not to the superior quality of the steel (Fig. 1).

The best guarantee of perfection in the tests of comparative efficiency can be obtained by a previously arranged scheme of experiments in agreement with the steel works which effect delivery. There are certainly tools also, the indisputable testing of which can be carried out only with great difficulty because of the length of time or high costs involved. It is, however, often possible to do without complicated comparative tests of such tools if the steel is ordered from a recognised high-grade steel works according to their specification; if, e.g., the high-speed steels of a works are reliably tested and deemed first-class, it can be taken for granted that the same firm supplies chisel steel, tap steel, hot pressing tool steel, etc., also of the best quality. Proper testing for efficiency of high-speed tool steels can be done most simply and reliably by comparison of turning experiments. Details of comparative turning tests are, therefore, given below for the determination of cutting efficiency. These rules have been confirmed as correct by a very important and extensive series of experiments. The number of experiments, of course, may be reduced or increased according to the size of steel required or the importance of the tests in other ways. It is, however, essential that before beginning them the plan of the experiments should be settled in agreement with all parties concerned.

Details of Comparative Turning Experiments to Determine the Cutting Life of High-Speed Tool Steels.

Steels Submitted and their Identification.—A bar 1 in. to 1·4 in. square, or better still a strip mill product of uniform width and 0·6 in. to 1 in. thick and about 80 in. long, must be submitted from every make of the steels to be tested. The bars must be stamped at the places indicated in Fig. 2. One of the 16-in. portions of every bar must be stamped apart from the mark stamp with the letter A, the other with the letter B. An identification stamp must be punched by the director of the experiments on all bars beside each mark stamp before beginning the tests. There should be only one copy of this stamp, and it should remain in the personal custody of the testing engineer.

Manufacture of the Cutting Tools.—Two cutters must be tested from every steel make to be tested. Both of the 16-in. portions of each bar must be cut off cold and then forged, rough ground, hardened, and tempered, and receive their final grinding to an edge on the unstamped ends, according to instructions or as directed by a representative of the supplier. If it is usual in a works not to forge the cutting edges, but to produce them from the steel cold, that is to say by milling or grinding, the edges of all testing cutters must be manufactured cold in the accustomed way.

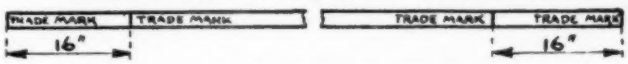


Fig. 2.—Stamping the test-bars.

Suitable furnaces, especially for hardening, or hardening and tempering baths or tempering furnaces must be available in good condition for treatment of the turning cutters.

All cutters must be given the cutting edges to suit the workpiece as shown in Fig. 3. The edges to be rounded to a radius r of 0·16 in. for the roughing test and 0·04 in. for the finishing test.

Storing the Turning Cutters.—All turning cutters must be under lock and key so that they can easily be inspected and kept in order, when not in use or when no dressing work is being done on them, particularly after the end of the day's work and during the midday break. The testing engineer should keep the key. Cutters are not to be released unless the representatives of at least two of the firms competing are present.

Workpiece.—The best workpiece is a rough turned shaft with a diameter of 10 in. to 15 in. and about 80 in. long of forged and annealed unalloyed steel of about 50 to 65 tons

per sq. in. tensile strength. In addition, a trial can be made on a roughed shaft of the same size of about 30 tons per sq. in. tensile strength. If the tools are also intended for machining cast iron, they must be tested on a similarly sized, roughed shaft of cast iron of as uniform a hardness as possible.

The workpieces must be tested for hardness at different places on the circumference after every fourth cut by a ball hardness testing machine. The variations in hardness shown by this test and due perhaps to existing hard places, layers of sand or slag, must be taken into consideration when judging the capacity of the cutters.

If other workpieces are used in default of those with the above properties, strict attention must be paid, especially in the case of castings, that all cutters operate on portions that are uniformly hard, scaly, sandy, slaggy, or porous.

Lathe.—The lathe provided for the turning experiments must be constructed firmly enough to work even with the heaviest cut and the highest cutting speed, without either appreciable loss of speed or chattering. Furthermore, the lathe must, if possible, allow of an infinitely variable cutting speed in order that the cutters may work under equal conditions after taking one or several cuts. If precise regulation of cutting speed is not possible, the workpiece must be divided into as many equal parts as there are steel makes to be tested (Fig. 4). Each cutter will work on one of these parts.

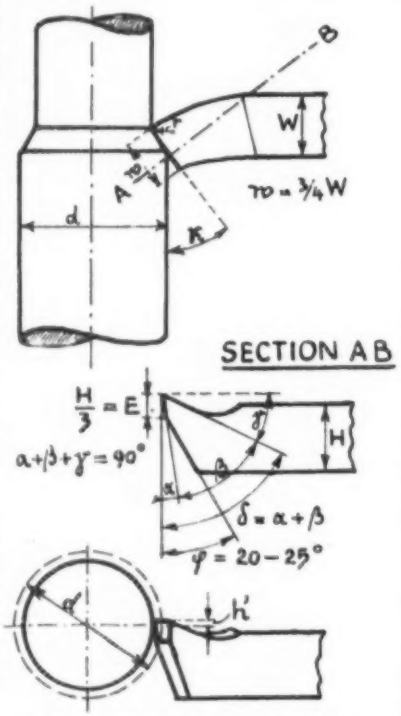


Fig. 3.—Cutting angles for high-speed tool steels.

Material.	Side Clearance Angle. α	Tool Angle. β	Cutting Angle in Plan. κ	Height of Cutting Edge above Centre of Workpiece. h'
All soft metals and pure aluminium	10°	40°	40°	
Tough and soft bronze and very soft steel	8°	55°	27°	
Steel and cast steel of 22 to 32 ton/sq. in. tensile strength	8°	62°	20°	
Steel and cast steel of 32 to 45 ton/sq. in. tensile strength; cast iron of Brinell hardness number less than 115; and soft yellow brass	8°	68°	14°	3% of diameter
Steel and cast steel of more than 45 ton/sq. in. tensile strength; hard cast iron with Brinell hardness number exceeding 115; cast brass, bronze, and yellow brass	8°	74°	8°	
Chilled iron and very brittle brass and bronze	6°	84°	0°	0%

Conditions of Cut.—For roughing experiments, it is best to choose a depth of cut of 0·2 in., measured vertically to the axis of the workpiece, and a feed of 0·06 in. per revolution. For finishing experiments, a depth of cut of 0·04 in. is most suitable, with a feed of 0·004 in. If local conditions require it, other proportions of cuts than the above may be agreed upon, but it must be seen that they are in complete conformity for all cutters. The height h' of the cutting edge above the centre of the workpiece and the cutting angle (κ in the plan) must be determined according to Fig. 3.

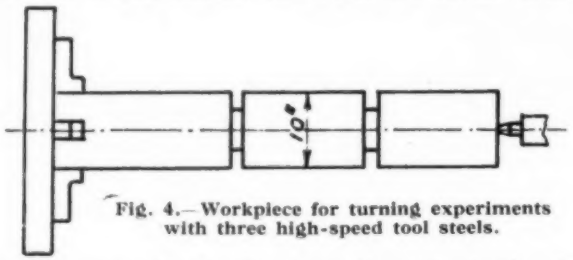


Fig. 4.—Workpiece for turning experiments with three high-speed tool steels.

Experiments with an increasing cutting speed, as when a disc is faced from the centre towards the circumference, deviate far too much from practical workshop turning conditions, and according to experience gained up to now they are not well suited for various comparative turning tests where the object is the judgment of high-speed tool steels.

A cutting speed must be chosen which is sufficiently high to take the edge off cutters of the makes of steel with the longest cutting life after an average cutting duration of about 20 mins. This cutting speed is ascertained by special trials which are not included in the final results of the test. The cutting speed chosen must be uniform for all the cutters that are to be tested on a workpiece.

The cutting speed is to be measured on whatever part of the shaft has been turned. All measurements must be done with the same speed indicator.

The appearance of a bright surface created by the tool "rubbing" is to be taken as the sign of blunting. If, during hardening or grinding, the edge of a cutter shows a crack which spoils it for turning, or if the edge breaks during turning without distinctly perceptible external reasons (that is to say, not due to faults in the workpiece or the lathe, etc.), the turning experiment in hand should be counted as completed, and the cutter must not be used again before the next experiment.

Operation During the Test.—The cutters must always operate on the workpiece in the same order, and as far as possible, at the same diameter; also, after working the cutter A of the first firm once, the cutter A of the next firm must be worked once on the same workpiece, then the cutter A of the third firm, and so on. If the cutters A of all firms have been tried once on one workpiece, the cutters B must be tested on the same workpiece in the same sequence. Then the re-ground cutters A are to be tested again on the same workpiece in the same order as before, etc., until all tests are completed.

The sequence of the firms for machining on a workpiece should be decided by drawing lots. The order must be allotted afresh for each workpiece.

The cutters are each generally used four times. They should be reground after the first blunting, and after the second blunting the old edge is to be rehardened and ground and then reground again. The place on the workpiece where the cutter in the previous test ceased to cut, due to rubbing, must be removed by a turning cutter which is not included in the test before inserting the cutter.

If turning is interrupted on a workpiece, the latter must

be stamped with the identification stamp at the point where the next cutter should start.

Testing and Representatives.—The consent of a representative of the contracting firm is necessary for all work on the steels and workpieces. Every firm has the right to have two representatives at the tests, and they may be present at all work, such as stamping the steels, cutting-off, forging, hardening, tempering and grinding, and during the turning and testing of the workpieces. On principle, at least one representative of a competing firm shall be present during the test of cutters supplied by a rival firm.

Report.—The following information must be included in the test report: Manufacturer, supplier, and trade name of steel, depth of cut and feed, cutting speed, duration of cut, data as to the workpieces, remarks about possible hard layers in the workpieces and special occurrences, such as improper cut, vibration of workpiece, etc.

The report must be compiled continuously so that the results at every stage of the tests and all events are recorded in writing at the time in the presence of witnesses, and not left until after the tests have been concluded.

Standards.—The centre portion left over from the tested bars can serve as a standard of efficiency of the steel for later deliveries. The piece is divided in two, one half being kept by the firm in question, and the other by the steel works which effect delivery.

Some Developments in Corrosion-Resistant Steels

Continued research on corrosion-resistant steel has not yielded a material which is universally insoluble, but a range of materials has been developed from which a successful choice can be made to provide a high degree of resistance to almost any corrosive media. Many corrosion-resistance problems still await adequate solution, and further types of steels are being developed by the addition of other elements and reference is made to the advantages of silver additions.

THE term "stainless," which is so frequently applied to corrosion-resistant steels, is the cause of some misunderstanding. It should be remembered that this term is used in a relative sense only, since there is no metal which may be considered universally insoluble; even the noble metals gold and platinum are no exception to this rule. Despite great strides as a result of scientific development there does not exist a corrosion-resistant steel which is serviceable under every condition encountered in practice, and it is extremely doubtful whether there will ever be such a material. But the stainless steels do show a greatly reduced resistance to corrosion over that of plain carbon steels and almost complete resistance to many media.

Broadly speaking, corrosion-resistant materials may be divided into two types: materials which are inert to any reaction with the surrounding medium, and materials on which the products of initial reaction are adherent and inert to further reaction with the medium. In the latter case, under proper conditions a protective film of inert material covers the entire surface exposed to the corrosive medium. With regard to corrosion-resistant steel, passivity and corrosion resistance appear to be due to the formation of invisible films of oxide, and such films have been isolated by U. R. Evans. It is well known that of all the possible different elements which may be added to steel, chromium is the most important and useful from the point of view of inducing resistance to corrosion. The films produced on chromium are continuous and adherent, and the addition of that metal to steel greatly increases the tendency to passivity. It is for this reason that a high chromium content, apart from other alloying elements, is an essential constituent in all corrosion-resistant steels.

The corrosion-resistant steel originally developed contained 12 to 14% of chromium, with percentages of carbon varying from about 0·45% up to about 0·60%; another contained a similar percentage of chromium but with carbon at 0·10%, or even lower. Both these materials have found an increasing field of usefulness despite the introduction of the more recent types of nickel-chromium steel. While not so generally resistant to corrosion as the latter, the lower cost of the original steels makes them of value in many special cases. They are especially useful where abrasive action is experienced, and in the large and important application for cutlery, since they have the capacity for hardening and tempering not found in the newer types of chromium-nickel steel.

It is not proposed to enumerate all the chemical media to which these steels are resistant; the range of applicability of the chromium-nickel steels is certainly very considerable, but there still remain special problems of corrosion which they do not adequately meet. It has been necessary, therefore, to develop further and more special types, among which are steels containing small additions of other elements such as tungsten, molybdenum and copper. More recent investigations have shown possible advantages of small additions of silver, and particular reference is made to this development.

Although continued research on corrosion-resistant steel has not yielded a material which is universally insoluble, a range of materials has been developed from which a successful choice can be made to provide a high degree of resistance to almost any corrosive media. It must be remembered, however, that in service conditions other factors must be considered in addition to corrosion resistance; for instance, the mechanical properties of the steel suitable for one set of conditions may be, and frequently are, unsatisfactory under other circumstances, and it may sometimes be necessary to sacrifice a certain amount of corrosion resistance in order to obtain hardness or other desirable property. Modifications may be necessary to facilitate fabrication or to improve machining qualities, and some sacrifice of corrosion resistance may be necessary to provide these properties. The fact that one corrosion-resistant steel, which is satisfactory in resisting the reaction of many media, may readily fail by the reaction of other media, and developments during recent years have been concerned with increasing the scope of these steels to meet special service conditions.

It is well known that a great variety of alloy steels, including some of the straight chromium steels, as well as the high chromium steels which contain sufficient nickel to make them austenitic, are perfectly satisfactory in their resistance to corrosion by nitric acid. From this range of chromium-alloy steels one may be chosen which will resist almost any concentration of nitric acid at practically any temperature from atmospheric to boiling. But this same range of steels, without further alloy additions, is readily corroded by solutions containing critical concentrations

of sulphuric acid, and more particularly to solutions of practically any concentration of hydrochloric acid, as well as some salt solutions like ferric chloride.

According to Landgraf,* the greatest success in the resistance to corrosion by sulphuric-acid solutions in general has been found among the alloys predominantly nickel bearing and containing a substantial quantity of chromium. In most cases the alloy is further augmented by minor additions of copper, molybdenum, etc. There are now available a number of alloys which contain a nice balance of these elements that are very satisfactory in their general resistance to corrosion by sulphuric-acid solutions, but the development of alloy steels which are resistant to hydrochloric acid, or even chloride-salt solutions, has not been so successful. He refers to a recent research at the Massachusetts Institute of Technology which may lead to the ultimate solution of this problem, and discusses some of the practical applications of the results of this research.

The major reason for failure of stainless steel in any of the chloride solutions is the formation of pits which more or less rapidly expand with time and ultimately penetrate the entire section, thus forming a hole. At the same time the area of the material immediately adjacent to the pit may be quite unaffected. This is readily demonstrated, for instance, in sea-water, particularly when the specimen is in contact with a foreign body. The product of corrosion is a chloride of the material which is being corroded. Applying the principle of corrosion resistance which relies for its effectiveness upon the fact that the product of corrosion is both adherent to and insoluble in the surrounding medium, the search is narrowed down to a corrosion-resistant material whose chloride salts are insoluble and adherent in an aqueous solution.

One of the metallic elements whose chlorides are practically insoluble is molybdenum, and even in concentrations of only 3% of the total corrosion-resistant alloy molybdenum certainly greatly increases resistance to corrosion ; for example, when added to the ordinary, low carbon 18/8 chrome-nickel stainless steel.

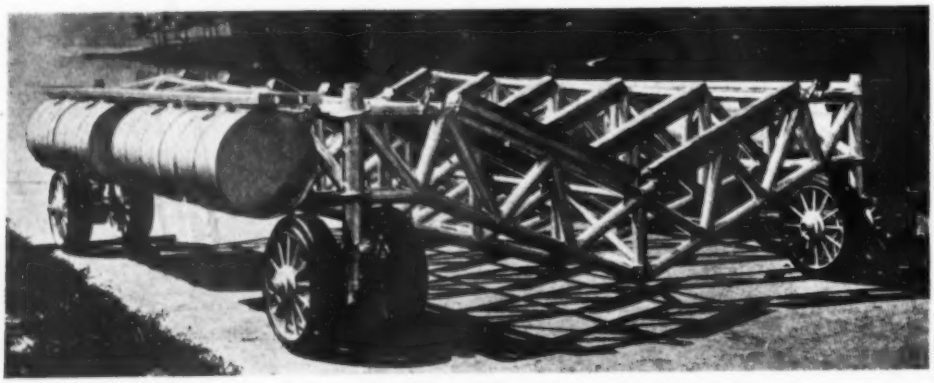
The major disadvantage in the use of a molybdenum-bearing alloy, even in applications where its corrosion resistance may be entirely satisfactory, is a more or less mechanical one. Molybdenum-bearing 18/8 is more difficult to machine than even the troublesome ordinary 18/8. Forging and drawing qualities of the molybdenum-bearing alloy are also limited, due to the extreme difficulty and in some cases practical impossibility of drawing it into such forms as tubing. Therefore the addition of molybdenum to 18/8 is bound to find practical restrictions due to the inherent difficulty of fabrication.

* Preprint 77-30 of paper presented at Seventy-seventh General Meeting of the Electrical Chemical Society.

Another element whose chloride is insoluble is silver, and after some considerable research it has been found possible to make silver additions to 18/8 sufficiently large to directly improve the pit-corrosion resistance, on the theory of the formation of the relatively insoluble silver chloride. However, the silver does not actually form an alloy with the 18/8, but it is held in suspension in minute evenly dispersed particles throughout the molten-alloy bath. Obviously the evenness or uniformity of dispersion of the silver will have a great deal to do with its effectiveness in preventing pit corrosion, since even the smallest unprotected surface may become the focus or origin of one of these malignant pits. Therefore, the effectiveness of silver as a pit-corrosion preventive is directly dependent upon the degree of control exercised in the completeness of its dispersion throughout the metal. This part of the problem is still a matter of intensive research.

One of the very real and at present definitely provable advantages of the silver inclusion is a tremendous increase in the machinability, as well as the forgeability of the 18/8 alloy to which the silver has been added. This phenomenon is largely due to the fact that the silver-bearing 18/8 does not have the tendency to work-harden as rapidly as the ordinary 18/8. Further, it has been demonstrated that the sllver addition made to a molybdenum-bearing 18/8 is just as effective in improving the machining qualities as it was in the ordinary 18/8. In fact the improvement is even greater, because the silver addition renders the 18/8 with molybdenum just about as machinable as silver-bearing 18/8 without molybdenum. By combining the effect on resistance to pit corrosion of molybdenum and silver, and appreciating the great improvement in machinability and general cold-working characteristics that the silver imparts to 18/8 with or without molybdenum, it is felt that further progress has been made in the development of corrosion-resistance alloy steels.

Although the range of corrosion-resistant steels available has grown to very large proportions, the choice of a suitable steel for a given set of conditions is very difficult and complicated and demands considerable experience. In some instances careful laboratory tests are made to assist the choice, but it should be remembered that these tests must be carried out in such a way that they repeat the conditions encountered in service, otherwise the choice cannot be regarded as reliable. It is the relative degree of resistance provided by these steels under specific conditions of service that determines the most suitable for a given purpose, and as a rule manufacturers are ready to place their wide experience and facilities for testing at the service of engineers faced with corrosion problems.



Landing carriage for flying boats, made in chromium-molybdenum steel. The tubular structure is heat-treated.

Some Steel Developments Applied to Aircraft

By L. Sanderson

Progress in the design and construction of the modern aeroplane and its engines is the result of developments in many directions, of which metallurgical developments are not the least important. For these notes the author summarises the more recent and promising applications of metallurgical progress relating to steel.

INEVITABLY the existing situation with its intensified production and development of aircraft for both military and civil purposes has led to progressive investigation of metals in their relation to aircraft, and also to research and experiment in parallel directions concerned with aircraft production. In the following notes are summarised the most recent and most promising applications and discoveries relating to steel.

For some time the desirability of employing a controllable pitch, quick-feathering propeller in aircraft has been an axiom. More and more in the way of performance and safety is being demanded of the modern aeroplane, and this, in combination with a rapidly growing range of speed and altitude, and an increased disposition to employ power descents, have reacted considerably on propeller design. The ability to produce what may be termed a rapid feathering propeller has been governed largely by the availability of suitable alloy steels. A propeller of this kind embodies bevel-gear segments and rotating cams, as well as bevel gears of the mating type, which have to withstand severe wear on the surface while retaining adequate strength in the core to resist the complicated stresses they are likely to meet with in service. A 5% nickel steel, case-hardened, has proved adequate to these requirements, while for the spider also forming part of the design a nickel-chromium-molybdenum steel quenched and tempered to give a Brinell hardness number of 375–415 has been used.

By the use of these alloy steels it has been found possible to manufacture a propeller that, while in ordinary use acting as a constant-speed propeller, can be used by means of a variation of pitch angle, and increased range of pitch angle change to furnish the best possible performance for modern airplanes. Furthermore, by a still further increase of blade pitch a position can be obtained in which the blades act as a kind of " feather " to stop engine rotation and cut out drag on the non-functioning engine in a multi-planed machine, one engine of which has failed.

Current practice in the manufacture of valves for aero engines has produced one extremely interesting and important development which may prove of great value. This is the coating of valves and inserts with an 80% nickel, 20% chromium alloy known as Brightray. According to Mr. F. R. Banks, who has carried out exhaustive tests with this material, valves so dealt with prove to possess an ability to withstand oxidation and a resistance to corrosion greater than that exhibited by aero valves faced with the cobalt alloy known as Stellite.

For other valves for aero engines, practice in both America and Great Britain appears to favour the employment of austenitic nickel-chromium steels for valves and seats, with a nickel-chromium-manganese steel for the inserts (12% nickel, 3·5% chromium, 5% manganese, 0·5 to 0·6% carbon). Sometimes this steel is Stellited, as is the austenitic steel. Attention should also be directed to the use of silicon-chrome material for inserts. Complete valves have also been made from Brightray, and the test results are said to be highly promising.

In the Unitwin twin-engined aeroplane, designed by the Vega Airplane Company, the engines are set side by side in the nose of the airplane and geared together by means of simple over-running clutches, driving one propeller. The propeller-drive mechanism has to possess a high resistance to fatigue together with high strength. Clutch cams must have high-core strength and be able to resist high roller pressures. Heat-treated nickel-alloy steels have been used for these cams, while 5% nickel-steel, case-carburised and heat-treated, has been employed for gears and drive cams.

Undoubtedly, however, the most revolutionary and possibly the most important advance has been the introduction of steel castings into aircraft manufacture, and particularly in the huge transport aeroplanes now being constructed in the United States of America. Military aircraft are also employing steel castings in their construction. The particular function fulfilled by these castings is as integral parts of the landing gear. Perhaps some impression of the importance of this new development will be gathered when it is stated that the Boeing Aircraft Company are using castings with finished weights of 81 and 59·5 lb., the rough weights being, respectively, 128 and 92 lb. The larger casting is a landing gear attachment, and the smaller a landing gear knuckle.

Particular interest attaches to the steel from which these castings were made. Various compositions were tried, none of which proved entirely suitable, but eventually a copper-silicon steel was developed and this gave satisfactory results. The analysis of the material is as follows: 0·12 to 0·2% carbon, 1·1 to 1·35% manganese, 1·0 to 1·25% silicon, 1·5 to 2·0% copper. The phosphorus and sulphur contents averaged less than 0·045%. The advantage of this steel was its fluidity at relatively low-pouring temperatures, which ensured the production of thin sections without flaws, and castings with clean surfaces. Welding is feasible. The castings are subjected to most stringent inspection and test, and the Magnaflux method of magnetic detection of cracks is consistently employed.

While the use of steel castings of this type in Great Britain has apparently not been adopted to any extent, the British aircraft manufacturers are taking keen interest in the development, and it is possible that before very long experimental work will be begun. Meantime, complicated stainless steel castings are being employed in aircraft construction by the Fairey Aviation Co., Ltd., and also by Hawker Aircraft. It is usual to subject these castings to radiographic test.

During 1939 the employment of chromium-molybdenum steels in aircraft has been considerably extended, as these steels, being air-hardening, and possessing high strength and excellent ductility, while being free from temper brittleness, offer numerous advantages to the constructor. Particularly for butt-welded sheet and tubing for aircraft have they proved satisfactory. An intense investigation into the occasional cracking of these steels when welded has been carried out by the Engineering Foundation Welding Research Committee, as a result of which it has

been established that the cracks are intercrystalline and take place at high temperatures in the region of from 500° to 1,100° C. High sulphur and phosphorus contents are probable causes in certain instances. Unsuitable welding processes may also cause this trouble, and the carburising flux technique has proved successful in preventing cracks in thin-walled tubing. Preheating also minimises cracking, while the thin sheets are more likely to crack than the thick. Careful deoxidation during manufacture of the steel is beneficial.

Considerable progress has been made in the application of austenitic nickel-chromium corrosion-resisting steels to aircraft. Complete wings, tail structures, wing-flap assemblies, wing ribs, pontoons and similar parts have been built both experimentally and in regular production. A seaplane constructed entirely of this steel—including the stressed skin covering of wings and hull—has been built. In Italy two well-known constructors of aircraft are using stainless 18/8 steel exclusively for highly stressed fuselage parts, seaplane floats, and structural parts of flaps, ailerons, rudders and tails. The greater strength, ease of fabrication and resistance to corrosion of this steel as compared with alternative metals has been fairly well demonstrated.

In France the Morane-Saulnier plane for military pursuit embodies many metallurgical features, indicating modern tendency in aircraft design. For example, the struts of the wing structure are made up of two bed-plates. These are manufactured from a steel of high strength, the composition of which is as follows: 0·25 to 0·35% carbon, 2·5 to 3·5% nickel, 0·8% chromium, and 0·3 to 0·4% molybdenum; it is heat-treated to give 84 tons per sq. in. tensile and an elongation of 12% minimum. Struts in the frame are made of nickel-chromium-molybdenum steel. The main frame to which the wing struts are fixed comprises two crossbars of nickel-chromium-molybdenum steel; 18/8 stainless steel is used for tubular rivets for joining frame parts, for principal ribs, frame reinforcements, cockpit cover and interior cabin fittings, radio short-wave antennæ for both transmission and reception, and for boxes for closing the openings where the sheet of the fire barrier is intersected by the breech of the bomb-carrier.

Having dealt thus with those steel developments actually incorporated into existing practice, it will now be as well to outline the more-recent discoveries and developments either about to be embodied in or worthy of examination in connection with modern practice. In the field of production one of the most important advances has been the introduction of the lead-alloyed steels for easy machining. It has now been demonstrated in both experiment and practice that the addition of lead to carbon steels of varying carbon content as well as to typical alloy steels suitable for machined parts of aircraft, etc., results in a considerable increase in the facility with which machining can be carried out. At the same time this addition does not in any way impair mechanical properties, ability to case-harden or harden, and the like.

Another discovery in connection with the use of austenitic 18/8 nickel-chromium stainless steels for seaplanes and other aircraft is the beneficial effect conferred by alloying the metal with small percentages of silver. Not only does this addition increase corrosion resistance when in contact with sea-water, but it also lessens the work-hardening effect, makes machining easier, and raises the thermal conductivity. Pit corrosion is noticeably reduced and a high surface polish can be given to the sheets. Sometimes a little molybdenum is added at the same time, and is said to give additional advantages.

The fractures frequently noticed in the diagonal tension wires in aircraft are probably caused by vibrations set up in flight. An extensive research into this problem has been carried out in Germany, and it appears that endurance strength is diminished by marginal carburisation and that the static strength is also reduced by bending and torsion. Chrome-molybdenum steel was found to have a higher static and endurance strength than unalloyed steel, especially in the hardened state. Heat-treatment, after cold-working at about 250° C., improved the bending strength in wires of both unalloyed and chromium-molybdenum steels.

The application of metallurgical developments to the aircraft industry has included many other promising improvements and discoveries, in addition to those relating to steel, and elsewhere in this issue the author summarises some of these developments.

Carbon Steel

(Continued from page 86)

specifications covering high-pressure reaction chambers and boiler drums involve higher strength, and the carbon content specified ranges from 0·28 to 0·32%; this grade is also specified for locomotive piston rods, marine shafting, marine gear-wheel rims, turbo-electric discs, shafts and rotors. Increased strength to meet certain specifications for marine shafting, locomotive crank pins, turbo-electric discs, shafts and rotors is supplied by 0·32 to 0·40% and by 0·40 to 0·50% carbon steel; for Diesel engine cylinder liners, and the forged rings for ball mills, the carbon content is 0·60 to 0·70%.

The range of carbon tool and die steels is very considerable and includes the 1·4% carbon steels for general lathe, slotter and planer tools, razors, draw dies, scale pivots, ball races, trimming dies, cutting dies, etc.; 1·2% carbon steels for twist drills, small taps, threading dies, edge tools in general, cutlery, cold-stamping dies, leather cutting, cloth and glove dies, etc.; 1·0% carbon steels for milling cutters, woodworking tools, forming dies, saws, small punches, taps, small springs, cam rollers, reamers, drifts, broaches, large cutting and trimming dies, etc.; 0·90% carbon steels for hand and pneumatic chisels and punches, drop dies for cold work, small shear knives, cutting and blanking dies and punches, etc.; 0·80% carbon steels for large shear knives, chisels, sledges, forging dies, hammer dies, boiler-makers' tools, vice jaws, etc.; 0·70% carbon steels for smiths' tools, set-screws and keys for automobile and general engineering use; 0·60% carbon steels for hot-working and battering tools in general, bolt and rivet headers, hot drop-forging dies, flatteners, fullers and wedges, etc.; and 0·50% carbon for machinery parts, quarry masons' tools, mining tools, axes, crow-bars, drifts, wedges, etc.

It has only been possible to mention a few grades of the large number available and to refer to a few of their applications. Although various efforts have been made to reduce the number of specifications so that selection can be made from a smaller number of steels, the qualities and properties required of steel in modern practice are so diverse that a wide range is necessary to satisfy the many characteristics desired. In determining the particular grade of carbon steel for a specific application it is customary to use a steel with carbon content as low as will give the required properties, but some carbon steels are used for an infinite variety of purposes, as, for instance, the soft-forging grade containing 0·25 to 0·35% carbon, which possesses a tensile strength of 26 to 36 tons per sq. in. in the normalised condition, with an elongation of 25%. With suitable heat-treatment the tensile strength of this steel is increased to 35 to 45 tons per sq. in., and the elongation remains about the same. High-tensile carbon steel, with a tensile strength in the normalised condition of 35 to 45 tons per sq. in., and 40 to 50 tons per sq. in., after suitable heat-treatment is one of the forging steels particularly suited for medium and heavy forgings.

The refinements in the control and processing of these steels are responsible for their increasing application to high-duty purposes, and although there will always be a distinction between alloy and carbon steels because similar refinements are being applied to the manufacture and processing of alloy steels, the economical advantages of carbon steels frequently result in their preference when a balance between cost and service required is satisfactory.

The Structure of Liquid Metals

By A. Latin, Ph.D.

The analysis of metals and alloys by means of X-rays is growing in importance with the increasing need of accuracy in determining their mechanical and chemical properties. Of fundamental importance in leading to increased understanding is a knowledge of the structure of many types of liquid metals, and the results of X-ray and related work in this field are reviewed and conclusions drawn from them are examined.

RECENT years have seen striking advances in our knowledge of metals, largely as the result of scientific investigation, and since it is mainly physical properties which determine the value of metals, physical methods of examination have become increasingly important. Some of these methods are rapidly becoming an ordinary part of metallurgical technique; of these, particular mention may be made of X-ray microstructure examinations which are being used to a growing extent in routine as well as fundamental research. In addition to increased knowledge of metals and alloys in the solid state, as a result of X-ray investigations, much information has been gained concerning the structure of many types of liquid, including liquid metals. Such knowledge is of fundamental importance in leading both to an increased understanding of the properties of molten metals and of the nature of the solid ⇌ liquid transition. The general question of liquid structure as applied to metals is dealt with in a paper* by Dr. A. Latin, in which he discusses different conceptions of liquid structure under two chief types of theory: "Group" and "Statistical" theories. Then he reviews the results of X-ray and related work in this field, and, finally, examines the possible conclusions that can be drawn from these results. The author's views expressed in this paper are of importance and provide a step of a fundamental nature in the solution of the many problems involving the solidification of metals in practice.

The X-Ray Investigation of Liquids

A full account of the diffraction of X-rays by liquids has been given by Randall.[11] A monochromatic beam of X-rays passed through a liquid gives rise to one or more diffuse diffraction bands (haloes). Debye and Scherrer[12] showed conclusively that the effect is due to interference. In earlier work only one band was usually obtained, but improved methods have shown the presence of more for many liquids. This existence of more than one band can be taken as a definite indication of some form of regularity in the liquid structure. On the assumption that Bragg's law applies to the liquid, the spacing calculated for the principal band agrees closely, in many cases, with that for the most intense line (principal plane) from the solid. With increase in temperature, the spacing usually increases, the bands become broader, and the "background" scattering becomes more marked. For some liquids, however, increase in temperature appears to have, within wide limits, little effect on the pattern. In other cases (e.g., water[13]) special effects occur which are probably connected with changes in the structural characteristics of the liquid.

For obtaining a detailed picture of liquid structure the intensity-diffraction angle (scattering) curves are of more importance than the mere positions of the bands, which correspond to the maxima of the curves. These curves may, of course, be obtained from the X-ray photographs by means of a microphotometer, or directly by means of an ionisation spectrometer. Various methods have been used for interpreting the curves. Stewart,[6] for example, has made use of his hypothesis of cybotaxis in connection with his results for water and organic liquids. At present three main methods appear to be in use: (1) a distribution function (i.e., a statistical "model") may be first assumed and the theoretical intensity curve derived by the method of Zernicke and Prins.[14] This is then compared with the experimental curve. Prins and Petersen[15] have improved on this by obtaining a general equation of the distribution function for monatomic liquids on the basis of the solid structure, "blurred" by the thermal agitation. The theoretical intensity curves are then derived from the Zernicke-Prins equation. They differ markedly for different space lattices and have shown good agreement with experimental curves. (2) The method of Debye and Menke[16, 17] does not require the assumption of a distribution function. From the experimental intensity curve, a probability function is obtained which expresses the probability of an atom being at a given distance from a given atom. The peaks of the probability curve therefore give an idea of the "quasi-crystalline" nature of the liquid. (3) From a Fourier analysis of the experimental intensity curve and an application of another form of the Zernicke-Prins equation, the radial distribution of atoms around an average atom in the liquid can be calculated. This last method promises to be extremely useful. It appears capable of giving more information than the Debye method, and shares the advantage that no *a priori* assumption of atomic distribution is required. For further details a review by Randall[45] will be found of value.

Results on Pure Metals

(a) *The Close-packed Metals* (*Co-ordination number* = 12.)

Only three metals of this group appear so far to have been examined by X-ray methods in the liquid state, namely, lead, aluminium and thallium. They have all face-centred cubic lattices in the solid state (thallium being in the β form before melting). The results for lead and thallium are summarised in Table I.

TABLE I.

Metal.	Bragg Spacings, A.		Reference.
	Solid (111) Plane.	Liquid Bands.	
Lead. M. p. 327° C.	2·85 (Room temperature.)	Single band at 3·07. *Temperature "just above" m. p.	Sauerwald and Teske.[18]
		Single band at 2·95. Temperature not given.	Randall and Rooksby.[19]
		Two maxima; principal band gives 2·90 ± 0·1. *Temperature "just above" m. p.	Danilov and Radtchenko.[4]
Thallium. M. p. 301° C.	2·80 (β)	3·05 1·55 1·13 Temperature 302° C.	Sauerwald and Teske.[18]

* Exact temperature not given.

* *Jour. Inst. Metals*, 1940, **66**, 177-190.

Randall[11] states that the results for aluminium agree with a close-packed structure for the liquid. No figures are given. For lead and thallium also, the intensity curves agree with a close-packed atomic configuration in the liquid. It seems possible therefore to draw the reasonable conclusion that metals which are close-packed in the solid state give rise to close-packed liquids on melting.

(b) *The Body-centred Cubic Metals.* (*Co-ordination No.* = 8.)

The alkali metals have received considerable attention. The results of Randall and Rooksby[20] and of Keesom[21] have been tabulated by Randall.[11] More recent measurements have been made on liquid sodium by Tarasov and Warren[22] and Trimble and Gingrich.[23] The results of the latter are of particular interest in indicating the effect of temperature. Three intensity maxima were observed at 100° C., the third (i.e., largest angle) one being very weak and practically disappearing at 400° C. The atomic distribution in the liquid was obtained by the Fourier analysis method. The curves of Tarasov and Warren (temperature = 103° C.) are reproduced in Fig. 1.

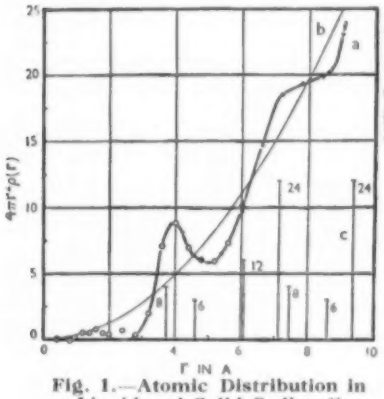


Fig. 1.—Atomic Distribution in Liquid and Solid Sodium[22]

Curve (*a*) represents essentially the statistical distribution of atoms (number of atoms in spherical "shells") at distance r from an average atom. It deviates periodically from curve (*b*) which can be taken as showing the distribution if the atomic arrangement were random. Comparison with the vertical lines, which represent the distribution in the solid, indicates a distinct resemblance. At 400° C. the distribution curve is of the same form but the peaks are less marked. The first peak at 100° C. occurs at 3·83 A. (i.e., there is here a concentration of atoms), which is comparable with the interatomic distance (3·72 A. at room temperature) in the solid. The value at 400° C. is 3·90 A. Wall[24] has devised an interesting form of distribution function for liquid sodium, based on the results of Trimble and Gingrich. He uses a model of a "quasi-solid" type, each atom being imagined as trapped in a spherical shell of radius σ. He shows that the function can be determined in terms of three parameters: σ, R_o = distance of closest approach of the atoms, and N_o = average number of nearest neighbours to an atom. His results for sodium are:

Temperature.	R_o.	N_o.	σ.
100° C.	3·79 A.	9·28 atoms	0·60 A.
400° C.	3·80 A.	8·95 atoms.	0·77 A.

The chief change is in σ, and this can be taken as indicating the increase in degree of irregularity with temperature (cf. the general distribution function of Bernal.[19]).

It seems reasonable to conclude that the structure of the body-centred cubic metals in the liquid state can be represented best by a "blurred" or "smeared-out" body-centred cubic "lattice." This is also shown by the agreement in type of the experimental X-ray intensity curves with the theoretical Prins-Petersen curve for this lattice. The curves differ from the close-packing type obtained for lead, etc., but do not disagree with a tendency for the appearance on melting of a closer-packed type of structure than corresponds to the body-centred cubic.

(c) *Metals Deviating More Markedly from Close-packing in the Solid.* (*Co-ordination number less than* 8).

The results for the metals of this type so far examined (six in all) are summarised in Table II.

All the results on mercury agree with an "ideal" close-packed atomic configuration in the liquid, the degree of irregularity increasing with temperature. Kratky[31] decided that a hexagonal close-packing fitted the results best. It seems probable, however, that there is little real difference between cubic and hexagonal close-packing in a structure so irregular as that of a liquid. The Prins-Petersen curves for both are very similar. Menke[17] calculated the most probable interatomic distance in the liquid mercury as about 3·2 A. (in the solid at—46° C. it is 3·0 A.). Sauerwald and Teske[18] showed that this agrees with the theoretical value, 3·25 A., calculated on the assumption of close-packing. According to them it is possible that deviations from close-packing and an approach to a structure more closely resembling the solid take place, perhaps in "groups," near the freezing point. The results on mercury are not supported by those of electron-diffraction investigations of surface structure. In earlier work,[32] a sharp pattern was obtained, but later work[33], [34] showed this to be due to a film of impurity. Diffuse scattering only was obtained. It should be realised that the X-ray results of Prins, like those of electron-diffraction, were obtained by surface reflection.

TABLE II.

Metal and Solid Structure.	Bragg Spacings, A. Chief Line from Solid.	Bragg Spacings, A. Liquid Bands.	Reference.
Mercury. Rhombohedral. N = 6. M. p. −38·8° C.	2·81 (111)	2·84 1·41 1·04 Temperature 18° C.	Prins;[25] Coster and Prins.[26] See also Sogani;[27] Wolf;[28] Debye and Menke;[16] Sauerwald and Teske.[18]
Tin. Tetragonal. N = 4, 2. M. p. 232° C.	2·78 (101)	2·29 Just above m. p. 2·83 Temperature not given. Three maxima; most intense at 2·8 (approx.). Temperature just above m. p.	Sauerwald and Teske.[18] Prins.[9] Danilov and Radtchenko.[4]
Bismuth. Rhombohedral. N = 3, 3. M. p. 269° C.	3·22 (100)	2·95 Temperature not given. 3·18 Temperature not given. Three maxima; most intense at 3·2 ± 0·1. Just above m. p.	Randall and Rooksby.[19] Prins.[9] Danilov and Radtchenko.[4]
Antimony. Rhombohedral. N = 3, 3. M. p. 630° C.	No results on liquid; pattern for amorphous solid agrees with "blurred" cubic.		Prins.[15, 29]
Selenium. Hexagonal. N = 2, 4. M. p. 217° C.	—	3·38 1·79 1·15 Very little alteration with temperature.	Prins.[9]
Gallium. Orthorhombic. Complex; see Hume-Rothery.[30] M. p. 30° C.	2·52 (200)	2·61 1·31 0·87 Temperature 45° C.	Menke;[17] Sauerwald and Teske.[19]

For liquid tin, Sauerwald and Teske concluded that the structure (perhaps in "groups") is related to that of the solid. On the other hand, Prins states that his intensity curve agrees with close-packing. Danilov and Radtchenko, however, obtained a curve which differs from the "mercury type" and shows similarities in position of the maxima with the X-ray pattern for the solid. These differences in results may possibly be due to differences in temperature (possibly also the effect of impurities, the influence of which on the patterns has not been determined), but serve also to illustrate the difficulties to be faced both in the experimental work and in interpretation of the patterns.

For bismuth also the results are conflicting. The band spacing obtained by Randall and Rooksby is identical with that for liquid lead, but it is not in agreement with the results of Prins or of Danilov and Radtchenko. The structure of solid bismuth differs widely from the normal close-packed structure of metals, but, as Randall and Rooksby point out, there are certain similarities to lead, its neighbour in the periodic system. They consider that liquid bismuth has a close-packed structure, and cite other evidence in favour of this view. Prins also concluded that liquid bismuth has a close-packed structure. On the other hand, Danilov and Radtchenko, using the Prins-Petersen method, concluded that a "blurred" simple cubic lattice fits their results best. The crystal lattice of solid bismuth, like that of antimony, is often considered as a slightly distorted simple cubic one. Prins's results on amorphous antimony are also in good agreement with a "blurred" cubic lattice. The results on bismuth are of particular interest in view of the large amount of work on melting and crystallisation phenomena in this metal. This will be discussed when the general conclusions of the present author on liquid-metal structure are dealt with.

With regard to selenium, Prins does not appear to draw any definite conclusions as to its liquid structure, but states that the pattern is identical with that of the solid obtained by quenching the liquid in water. Since it seems almost certain that there will be "microcrystalline" regions in the latter, it may be concluded that some sort of "quasi-crystallinity" exists in the liquid.

The solid structure of gallium is complicated and deviates very greatly from that of normal metals. It would appear that some degree of molecular binding exists. Menke examined the liquid (melting point = 30° C.) both at 45° C. and super-cooled down to 18° C. The intensity curve shows a pronounced "ridge" near the principal maximum, this becoming weaker with increasing temperature. A similar effect occurs with water. The probability curve shows a maximum at about 2·8 A., which, according to Sauerwald and Teske, deviates markedly from that which would be expected for closest packing (2·65 A.). The most reasonable conclusion from Menke's results would seem to be that the tendency for molecular binding persists in the liquid. It seems possible also (although there is no proof) that the appearance of the ridge indicates the presence of cybotactic groups, especially in the undercooled liquid.

Results on Alloys

The alloys of sodium and potassium have been investigated in the liquid state by Banerjee.[35] In the solid alloys the intermetallic compound Na_2K forms, and Banerjee has decided that his results point to the existence of this compound in the molten state also, in particular near the freezing point.

The compounds Hg_5Tl_2 and KHg_2 have been investigated in the molten state by Sauerwald and Teske.[18] They find for Hg_5Tl_2, as does Banerjee for Na_2K, a decided maximum at a smaller angle, i.e., corresponding to a longer spacing, than for either of the pure components. The conclusion is that molecules of the compound tend to persist in the melt, particularly near the freezing point. For KHg_2 the two principal X-ray intensity maxima correspond roughly in position with those for the two components, but Sauerwald and Teske show that it is probable that this compound also persists in the molten state. The apparent correspondence of the patterns is due, according to them, to the large volume contraction which occurs when the compound forms, and the pattern for the alloy is shown to be in agreement with the presence of KHg_2 molecules. These results on intermetallic compounds therefore throw light on the vexed question of the stability of these substances in the molten state. Bornemann[46], [47] has shown how studies of the electrical conductivity of liquid alloys give an indication of the stability of intermetallic compounds. His results would appear to indicate a high degree of stability for KHg_2 and $NaHg_2$, and a lesser one for Cu_3Sb, whilst Na_2K is highly dissociated in the liquid state.

Four eutectic alloys, bismuth-tin, tin-lead, lead-bismuth, and tin-zinc, have been investigated in the liquid state by Danilov and Radtchenko.[36] They show that the intensity curves may, to a first approximation, be built up by adding those of pure components, making allowance for the relative masses of the two components present. They conclude that the two types of atom are not (near the freezing point) completely intermingled, but that small separate regions, consisting of the practically pure metals, tend to form. The structure of the solid eutectic is thus "foreshadowed" in the liquid. Whilst a more rigorous method of interpreting the X-ray diffraction diagrams is desirable before this conclusion can be accepted without reserve, it seems not unreasonable, particularly if, as will be seen presently, cybotaxis is assumed. On the other hand, Prins[9] obtained for Wood's alloy a pattern similar to the mercury type.

General Conclusions

It is evident that much work, both experimental and theoretical, remains to be done. Nevertheless, it is possible to draw certain conclusions of a general nature. Of these the most outstanding is that the forces responsible for the structure of the solid metal or alloy persist to some extent in the liquid. From one point of view the liquid structure can be regarded as a highly distorted form of that of the solid. Perhaps this can be most clearly pictured from what has been called the "hole" conception. Imagine some of the atoms removed from the lattice of the solid in a similar way as is done for the so-called "subtraction" structures, for example γ-brass. Now imagine the rest of the atoms rearranged so as to fill up the spaces left as regularly as possible. If, in addition, the atoms are given large vibratory and translatory motions about their mean positions an irregular "structure" results which corresponds to that of the liquid.

Another very useful conception has arisen from comparison of the solid $\rightleftharpoons$ liquid transition with order $\rightleftharpoons$ disorder changes in solid alloys. This has been used, for example, by Lennard-Jones and Devonshire[41] in their highly successful theory of melting. They have applied the theory to a face-centred cubic lattice, taking argon as an example. Wannier,[48] too, has applied the idea of melting as an order-disorder transition to a diamond-type lattice. Frank[49] also has dealt with this conception in a general manner, and has shown that it gives an insight into the phenomena of supercooling and nucleus formation. The fundamental assumption in such theories is that melting can be conceived as a *continuous* transition from the ordered state of the crystal to the disordered state of the liquid. The similarity between solid and liquid is further stressed by the fact that, as the phenomenon of diffusion in the solid state shows, translatory atomic movements can also take place in the solid. On the other hand, it seems to the author dangerous to carry this conception of similarity too far; it is best to avoid, for example, the application of a term involving the notion "crystalline" to the liquid.

In addition to this it seems possible to arrive at further conclusions of a useful nature:

(1) The solid $\rightleftharpoons$ liquid transition in the face-centred cubic, hexagonal close-packed, and body-centred cubic

metals is "homomorphous," or practically so. That is to say, the solid melts to form a liquid of very closely allied structural characteristics. This is also indicated by the relatively small change in density and specific heat on melting, and the much smaller tendency for super-cooling shown by these metals[1], [3] than by metals like bismuth, gallium, etc. The melting process is probably of a "sharp," i.e., essentially discontinuous, nature. The theoretical work of Bernal[10] (which has been criticised, however, by Frank[49]) on a general distribution function for monatomic liquids supports this view, as well as his arguments that it is not possible to obtain a continuous series of distribution functions between that for the solid and that for the liquid. Furthermore, there seems to be no definite reason for assuming group formation of either a "microcrystalline" or cybotactic type in such liquids.

(2) For molten metals of which the solid structures deviate more or less largely from close-packing, the solid ⇌ liquid transition is "morphotropic," i.e., there are differences in structural characteristics between solid and liquid. Bismuth and gallium are outstanding examples, and metals like mercury and tin may possibly be regarded as occupying intermediate positions.

In liquid metals of this type, there may be said to be, to simplify matters to the utmost, two opposing tendencies: (*a*) a tendency for close-packing, following a release of the atoms from the solid "bondage," and (*b*) a tendency for configurations to occur related to the crystal structure of the solid, owing to persistence in the liquid of forces acting on the atoms in the solid. Bismuth and gallium contract on fusion, but this contraction, according to the calculations of Sauerwald and Teske,[18] is less than would be expected if the closest-packing were to result. There seems some reason to suppose that the transition is not of so "sharp" a nature as with the close-packed metals. There are several experiments which indicate this for bismuth.[37], [38], [39], [40] The assumption of a definite mesophase between solid and liquid does not, however, seem to be entirely justified at present. On the other hand, the hypothesis of cybotaxis gives, in the opinion of the present author, a good explanation of the phenomena. It seems very likely that the two opposing tendencies described above give rise to groups of a transitory nature, i.e., cybotaxis, which will be most marked just above the melting point. At the same time the tendency for close-packing will increase as the temperature is raised and probably reach an optimum value. Beyond this stage the normal expansion with temperature increase is probably accompanied by an increased irregularity of the atomic configuration. These conclusions are also in line with the relatively high degree of super-cooling that tends to occur, as well as with the changes in diamagnetism and electrical resistance[50] that occur on melting. It is of interest to note that order-disorder changes in solid alloys are frequently accompanied by changes in the crystal structure. It might well be expected, therefore, that in some cases analogous changes in structural characteristics occur on melting.

(3) Cybotaxis of a sort seems also not unlikely in molten intermetallic compounds. The X-ray results for these can be interpreted in two ways: (*a*) there is some tendency for molecules of the intermetallic compound to persist in the liquid; and (*b*) there is a tendency for atomic configurations in the liquid to resemble those in the solid. Since the forces responsible for compound formation and for crystallisation are undoubtedly related, these two statements are probably equivalent. That a form of cybotaxis is likely arises from the reasonable view that the atoms in the liquid are not permanently associated, but that the compound is, so to speak, perpetually forming and dissociating.

(4) The X-ray results for the eutectics can also possibly be best explained by the assumption of a form of cybotaxis. The general conclusion, obtained from much evidence besides that from X-ray work, that the forces acting in the solid state tend to persist to some extent in the liquid, makes the assumption of a tendency for separation of the components of a eutectic alloy in the liquid near the freezing point not unreasonable. It is very unlikely, however, that the regions consisting of one or the other of the more or less pure metals are of a permanent nature, but more likely that the atoms of the different metals are continually tending to intermingle and separate. Since they are in continual agitation it will be seen that this is feasible.

It is possible that these views may have to be modified in the light of further knowledge. Nevertheless, it is hoped that they will be useful as representing a wide attack on a subject of importance, as well as one step of a fundamental nature in the solution of the multifarious problems involving the solidification of metals in practice.

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Iron and Steel Control

THE Minister of Supply has made the Control of Iron and Steel (No. 11) Order (S.R. and O., 1940, No. 1138, price 1d.), which came into force on July 8, prohibiting, with certain exceptions, the use of iron and steel for buildings, except under licence.

The intention of the new Order is to prohibit the consumption of iron and steel already in the hands of contractors or consumers and the sale of iron and steel by stockholding merchants for non-essential buildings. No licence will be required for the use of steel for building, where the purchase of that steel has been authorised by a Department for that purpose under the Steel Distribution Scheme, or has been licensed by the Ministry of Supply (iron and Steel Control) on or since April 1, 1940. In order to cover urgent requirements for repairs and maintenance, the use, or the purchase from a stockholder, of less than 1 ton in one month for any particular building is exempt from the licensing scheme.

In present circumstances the Minister considers it necessary to prevent any use of iron and steel for non-essential buildings, and licences will only be granted for its consumption for buildings not already authorised, when it can be shown that the building will serve a useful purpose in connection with the war effort.

Any application for a licence to use iron or steel under this Order should be made to the Department to which application should be made for authority to purchase steel under the Steel Distribution Scheme.

British exports in May totalled £45,500,000, against an average of £44,900,000 for the months of March and April.

Metallurgical Developments Applied to the Aircraft Industry

By L. Sanderson

In a relatively few years the results of metallurgical research have made possible remarkable progress in the aircraft industry, but efforts are continually being made to improve existing materials or to discover new ones, and in this article are summarised further recent developments in this field.

THE value of research to the aircraft industry in the past has been of a high order, and, in view of what has been done, there can be no doubt that, both now and in the future, even more valuable work will be accomplished, and there is no question but that this industry will absorb the results. The following notes summarise some of the more recent results of metallurgical research applied to aircraft.

Aluminium Alloys

The employment of the aluminium alloys in aircraft engines is rapidly increasing. As an example, the Rolls-Royce Merlin engine may be quoted, in which Hiduminium RR50 (an alloy of aluminium with from 0·8 to 1·75% of nickel) is being employed for castings called upon to resist severe stresses, such as cylinder blocks, crankcases, and the like. In the same engine, pistons are being manufactured from a slightly different analysis of the same metal in the form of forgings, the nickel content being about 0·5 to 1·5%.

An American light aero engine developing 50 h.p. at 2,400 r.p.m. has employed cylinders individually cast in an aluminium-nickel alloy into which liners of nickel-chromium cast-iron have been shrunk. As the alloy iron liners expand under operating conditions to an extent virtually identical with the expansion of the aluminium-nickel alloy, excellent contact is maintained so as to diffuse the heat. Furthermore, the valve seats and exhaust-valve guides have also been made from the same nickel-chromium cast iron.

Magneto design in aero engines has been revolutionised by the employment of permanent magnets made from the nickel-aluminium and nickel-aluminium-cobalt magnet materials. Experiments are now being made with new magnet materials, and some notes on these are given later. A considerable reduction in the magnetic system and the surrounding structures has already been achieved with the current magnet metals.

The well-known Y alloy, containing copper, nickel, magnesium and aluminium, has been used with success for light-weight metallic sheets in various types of construction. It has now been found that the properties of this metal are improved by the addition of vanadium. The introduction of this element gives a better grain structure, easier casting where cast parts are required, greater impact strength, and a higher elongation. The metal is readily heat-treated.

Nickel and Nickel Alloys

A point worthy of note is the advantage of pure nickel as a material for sparking-plug electrodes in aircraft. Flight tests of from 20 to 30 hours' duration have shown that this metal possesses remarkably good properties for the purpose, particularly an ability to resist erosion. Nickel-rhodium alloys have also been tried for the same electrodes, but have not been found so good as pure nickel.

Another new alloy that may develop along economic lines is "Z" nickel. This contains 98% of nickel, and it is claimed to save from two to two and a-half times the mechanical strength of structural carbon steel. It can be worked in the unhardened state almost as easily as pure nickel, and can be heat-treated after fabrication with only a minimum of distortion. The metal is too recent for its commercial exploitation to have proceeded far, but it has already been used successfully for hand tools, spring clamps, spring coils, and a number of electrical uses, e.g., radio antennae.

Nickel-iron alloys containing from 36 to 50% nickel are being largely employed as thermostatic bimetals for the low expansion side, and for high expansion, alloys containing 22% nickel plus 3 to 8% chromium, the rest being iron. Typical uses for these alloys in the aircraft industry include automatic chokes, altimeters, fuel converters, oil guages, petrol gauges, carburettor heat control, water-temperature control, manifold heat control, shock absorbers, and windshield defrosters.

Some progress has been made, also, in the employment of nickel-chromium-iron alloys for exhaust manifolds, heating devices, and fire-walls. Nickel-copper alloy is also being employed with advantage for exhaust manifolds or collector rings. Monel metal is being adopted for filter cloth in petrol lines, for valve seats and tanks, and for lavatory, galley and cabin trim. France in particular has paid attention to the possibilities of this metal in aircraft design.

Magnet Alloys

Reference has been made to Alnico and Alni magnet alloys for permanent magnets for aircraft use. A noteworthy development in this direction is an alternative method of making up magnets from these particular alloys by compressing them in powdered form in dies together with bakelite or shellac as a bond, and heat-treating in order to obtain a solid mass. While a magnet thus manufactured will not have quite the same coercive force as a solid magnet, the difference is only from 5 to 10%. As the remanence is only about 10% less, and the density of the powdered material is considerably lower, the performance, weight for weight, is little less than that of a solid magnet of the same alloy.

A new range of magnet alloys containing iron, nickel, cobalt and titanium, have been produced, and these are said to have a higher energy content than even the Alnico magnets. The analysis is approximately as follows: Cobalt 30%, nickel 16%, and titanium 12%, the balance being iron. These new alloys are, however, expensive to make, and the cost per unit of energy is higher than that for the ordinary Alni alloys, so that at the moment the commercial utilisation of this new range has lagged.

This brief summary of developments in permanent magnet materials would be incomplete without reference to the various experiments now being carried on with the production of sintered materials for magnets. Iron oxide and cobalt ferrite ($CoFe_2O_4$) sintered together are a typical example. Silver-manganese-aluminium and neodymium-iron alloys have been tried, and the latter, in particular, has a high coercive force (4,300). Platinum-iron, platinum-cobalt, palladium-iron and palladium-cobalt are other materials possessing high magnetic properties that have been investigated. So far, the results are of purely academic interest.

Alloy Cast Iron

An interesting development is the employment of a manganese nickel cast iron for the cylinders of a light aero engine of French design. The intention of the de-

signers was to produce an engine for private aircraft low in cost, but of higher power per weight unit than similar existing engines. The cylinders were air cooled, and it was necessary that they should be of a high strength, high elastic modulus, have excellent wear-resistance and freedom from galling, combined with adequate fluidity in casting so that the fins could be thinned down to the maximum. The type of alloy iron eventually found satisfactory contained 2·8% carbon, 2·0% silicon, 1·2% manganese, and 4·2% nickel. It was found that the adoption of this alloy cast iron effected a reduction of 7 to 8% in the total engine cost as compared with forged steel cylinders, while the increase of weight involved did not amount to more than 5%. In use, wear proved to be considerably less than that of steel.

A new alloy iron has been developed for crankshafts for petrol engines. This contains 1·74% carbon, 0·62% silicon, 0·63% manganese, 0·05% sulphur, and phosphorus the same, 1·94% nickel, and 0·64% molybdenum. This iron has a high strength and good casting characteristics.

Hard Facing Alloys

The hard facing and rebuilding of parts by welding has made further progress, and among the different iron-base alloys available for this work, it is claimed that molybdenum iron alloys, whether chromium is also present or not, offer special advantages. They are very strong, tough, and give a uniform deposit, which means added resistance to wear. Complete freedom of the facing from pinholes or cracks is another important advantage claimed.

A hard-metal alloy recently developed in Holland contains tungsten, carbon and cobalt prepared from a powdered mixture of the constituents by sintering. An interesting development is the introduction of titanium cyanonitride into high chromium austenitic corrosion-resisting steels as used for exhaust valves of aero engines. The object of this addition is to serve as a source of nitrogen, which has the effect of improving the grain structure of the metal as well as its mechanical properties, while the titanium acts as a stabiliser, preventing weld decay.

Further Developments

The employment of the bi-metallic alloys is also making important progress. One interesting employment of these metals is in the thermostatic control of cylinder-wall lubrication. The cylinder walls when cold are lubricated in advance of ignition, and the starting up of the engine, which has the advantage that the severe wear usually occurring before the regular oil supply begins to operate is minimised. Low-expansion alloys containing nickel have also found an advantageous outlet in the form of struts in aluminium-alloy pistons for the purpose of keeping down the piston's overall expansion to an extent much nearer to the expansion of the cylinder in which it functions.

On the production side, the discovery of a new hard-cutting alloy for tools must be indicated. This obtains its hardness from crystalline chromium borides combined with an "unknown" crystal termed "X." It is claimed that this new alloy is lighter than tungsten carbide. Up to now it has mostly been employed in the hard-facing of various parts, when it is applied in paste form and sweated on. The crystals of boride alloy with the basis metal, while "X" crystals permeate the mass as if retained in an emulsion. The actual cutting properties of this new material have as yet not been thoroughly tested in practice.

In the field of bearings, attention should be paid to the increasing employment, despite their high first cost, of copper-lead alloys for bearings. These contain from 68 to 60% of copper, 7 to 5% tin, and 45 to 25% lead. Sometimes a little nickel is added. They (the bearings) are usually of steel with the copper-lead alloy applied as an extremely thin layer. The special methods of manufacture mean a high production cost, which has thus far tended to limit their use, but their high loading capacity is an important advantage, and research may lead to a lessening of cost and a consequent wider field of use.

In the protection of metal surfaces against corrosion, the invention of nickel-cobalt plating must not be overlooked. This type of plating is mainly advantageous as a kind of underlay to the chromium plating, and its use is believed to increase the corrosion resistance offered by the various types of chromium plating.

At first sight the colouring of stainless steel might seem to have no other than a purely decorative or ornamental effect, but it does not require a great feat of imagination to conceive the possibility that it might be of value in the camouflaging of seaplanes constructed of stainless steel, or embodying stainless surfaces to any extent. Various processes for colouring stainless steel have been developed. Some embody etching, others darkening, and others again, a direct colouring process, the particulars of which have not yet been published. So far as experiments show, the new secret colouring process does not in any way affect the corrosion resistance of the steel.

A silicon-aluminium alloy for piston rings deserves a note. This is an American discovery. In addition to piston rings it can be used for pistons. It has a lower thermal expansivity than any other commercially-employed aluminium alloy. It has a very much better elastic modulus (15,000,000 lb. in the square inch) than other alloys for piston rings. Marked benefits in engine operation are obtained from the use of this alloy, partly on account of its light weight, and partly because of its high thermal conductivity. At the same time it is not difficult to cast or machine, and is not highly expensive.

Some experiments have been carried out with uranium as an alloying element in metals. These have led to interesting discoveries, which may ultimately become serious factors in the metallurgical world. For example, it has been ascertained that a nickel-uranium alloy containing 66% of uranium is remarkably resistant to corrosive attack. It is reliably suggested that further experiments in the direction of adding other alloys to this combination may produce a new range of corrosion-resisting metals of economic importance.

Method of Estimating Tellurium in Tin Alloys

IT was shown by Dr. Hanson and Dr. Pell-Walpole some time ago that a little tellurium improves the creep strength of pure tin, both in the rolled and the cast conditions. A convenient method of determining tellurium in these alloys has been worked out by Dr. Pell-Walpole. He ascertains the loss of weight that occurs on distillation *in vacuo* when tin telluride (Te Sn) distils without dissociation. A note of the method forms Publication 96 of The International Tin Research and Development Council, Fraser Road, Greenford, Middlesex.

British Standard Specifications. Cold-Rolled Copper Sheet

IT is rather surprising that so far there has been no British Standard Specification for copper for general engineering purposes, although there is a useful series of Specifications for copper for electrical purposes.

This deficiency has now been made good and a British Standard for cold-rolled copper sheet and strip (half-hard and annealed) for general engineering purposes has now been published. This Specification supersedes the Specification which existed in the Aircraft series—No. 2 B.15—for copper sheets for aircraft purposes, and which will now be withdrawn.

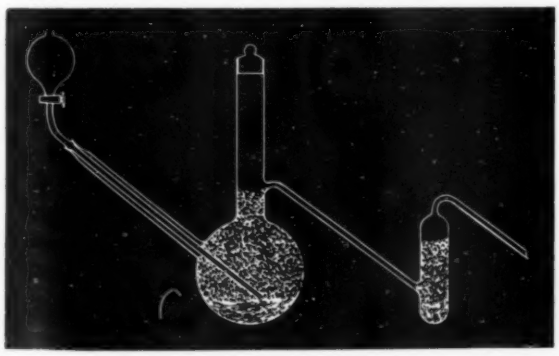
The composition clause has been so framed that an arsenical copper can be provided under the Specification if desired. The tensile strength of the material is 17 to 21 tons for half-hard material and 13·5 to 17 tons for annealed material, in thicknesses from 3 S.W.G. (0·252 in.) and thinner, and in widths up to 42 in.

Copies of this new British Standard (No. 899), may be had from the British Standards Institution, 28, Victoria Street, London, S.W. 1, price 2s. 3d. post free.

Preparation of Anhydrous Aluminium Bromide

AMONG the advantages possessed by aluminium bromide over aluminium chloride as a catalyst in certain organic reactions are its greater solubility in hydrocarbons, and its higher catalytic activity. It is also susceptible of being purified by distillation. A simple and convenient method for preparing anhydrous aluminium bromide is described by Winter and Cramer,* which gives a relatively high rate of production with a minimum of operating difficulties.

The apparatus is shown in the accompanying diagram. The bromine is introduced near the bottom of the reaction flask where it comes into contact with the aluminium chips or pellets. The flask may be warmed gently at first to start the reaction, but in a short time the reaction supplies enough heat to vaporise the incoming bromine and to distill the aluminium bromide out through the side arm on the neck of the flask, where it condenses and flows into the auxiliary purifier. The molten aluminium bromide refluxes down through the mass of aluminium chips in the flask, and serves to prevent local overheating and consequent fusion of the metal. The bottom of the flask is protected against occasional molten globules of aluminium by a layer of glass wool. The bromine tube must not be joined to the flask by a permanent glass seal, because it must be removed and cleaned occasionally when the lower end becomes clogged with solid impurities coming from the technical grades of bromine and aluminium. A ground-glass joint will serve nicely, but is not necessary ; the loose joint shown in the diagram may be sealed satisfactorily by an easily broken cement of pumice, water glass, and water. The level of this joint should be above that of the exit tube to avoid having the aluminium bromide reflux over it. The mouth of the flask is closed by a loosely fitting glass stopper



Apparatus for the preparation of Anhydrous Aluminium Bromide.

As the reaction proceeds, aluminium is consumed largely from the centre of the flask, and the bromine finally begins to channel up through and be carried over with the aluminium bromide. When this occurs, the supply of bromine is shut off, the stopper in the neck of the flask is removed, a hole is punched through to the interior of the mass of aluminium chips by means of a heavy glass rod, and the flask is refilled with aluminium chips.

The initial product as it distills from the reaction flask is usually nearly water-white, and may be collected at that point in a reaction vessel for immediate use or in a flask for storage. Sometimes, however, it is contaminated by a little free bromine and by impurities carried over mechanically. For this reason it is best to run it directly from the reaction flask to the bottom of a small distilling vessel filled with aluminium chips. Auxiliary heating is required to distill the aluminium bromide out of the purifier. A clean water-white product is thus obtained in a continuous process. For convenience in storing and subsequent use, the best receiving vessel is a distillation flask, whose neck and side arm are constricted for convenience in sealing the flask after it is filled. Before the reaction is started, the whole system should be flushed out with a dry gas (air or nitrogen) in order to avoid hydrolysis of the aluminium bromide. The side arm of the receiver should be provided with a guard tube to prevent the entrance of moisture. When the flask is about three fourths full, the reaction is stopped, and both the neck and the side-arm are sealed. The aluminium bromide thus collected can be stored indefinitely without deterioration, and smaller quantities can be withdrawn by cutting off the tip of the side-arm and distilling the desired amount into the dry reaction vessel ; then the side-arm may be sealed again.

The size of the apparatus is governed by the production rate desired. A 1-litre reaction flask can easily produce a kilogram or more of aluminium bromide per hour. The rate of production is controlled by the flow of bromine, and is limited by the condensing capacity of the receiver and by the maximum safe temperature within the reaction flask, which is just under the melting point of the aluminium. The apparatus described has ample capacity to supply aluminium bromide for laboratory uses, and there is no apparent reason why the principles involved might not be employed on a much larger scale, should the occasion arise.

* *Ind. Eng. Chem.*, **32**, 6, pp. 856-7.

Import Duties Exemption Order

Machinery, Aeroplanes, Bearings, Ploughs and Machinery Belting.

THE Treasury have issued the Import Duties (Exemptions) (No. 7) Order, 1940 (S.R. and O., 1940, No. 1140), which adds to the free list machinery, including machine tools, aeroplanes and seaplanes, ball and roller bearings, ploughs and machinery belting. The Order came into operation on July 8.

A number of exceptions to the operation of the Order relate to items of machinery chargeable with duty under Groups of the Tariff other than Group X. Among such exceptions are motor-cars, motor-cycles and cycles, clocks and watches, musical instruments, telegraph and telephone apparatus and electrical bell and electrical cooking apparatus.

One effect of the Order is to free-list the machinery for which licences could hitherto be issued under Section 10 of the Finance Act, 1932. The system of issuing duty-free licences for machinery under that Section, which has been operated by the Treasury in consultation with the Machine Tool Control and the Duty-Free Section of the Import Licensing Department of the Board of Trade, will thus automatically be brought to an end. Outstanding applications for duty-free licences in respect of machinery imported before July 8 will be dealt with as expeditiously as possible. Importers holding Treasury licences covering machinery which will be imported after July 8 should return them to the Secretary, H.M. Treasury, Whitehall, London, S.W. 1.

The removal of the duty on machinery does not, of course, remove the necessity of obtaining Import Licences.

The Treasury have also made a complementary Order entitled the Safeguarding of Industries (Exemption) No. 11 Order, 1940 (S.R. and O., 1940, No. 1141, price 1d.), the effect of which is to exempt from Key Industry Duty any component parts of machinery of the kinds free-listed by the Import Duties Order mentioned above which would otherwise be liable to such duty.

Reviews of Current Literature

Steel Manufacture Simply Explained

MANY people who are intimately associated with the use of steel, and even some who are engaged in the steel industry, have only the haziest idea of its manufacture. Why they should be content to remain in ignorance of this subject, which should be of immediate interest to them, is difficult to understand. It may be that in this age ofspeed the subject is too complex and difficult to grasp in a short time from normal textbooks on steel manufacture. For such people this little book will be especially useful. It is a companion to the book entitled " The Structure of Steel—Simply Explained," by the same authors, published about two years ago.

The authors appreciated that all those concerned in the many phases of the steel industry, or in using steel, are not expected to be specialists in the manufacture of steel, but recognise that there is a desire for a simple explanation of many aspects of what is a complex subject. In this book the authors deal briefly with all the various processes of steel-making, from the ore to the semi-finished product, and present the information in such an admirable way, without much sacrifice of accuracy, that the unitiated can readily grasp the fundamental aspects. The authors have succeeded in making every stage of every process so clear that they should easily be understood by the layman, as well as by the student and the engineer. The book is full of useful information and data presented in are adable and comprehensible form.

By Eric N. Simons and Edwin Gregory, Ph.D., M.Sc., with a Foreword by C. K. Everitt; published by Sir Isaac Pitman and Sons, Ltd., Parker Street, Kingsway, London, W.C. 2; price 6s. net.

The Metallurgy of Deep Drawing and Pressing

THE formation of shaped metal articles by severe plastic deformation is not by any means a new craft; it dates back to very ancient times, and, in some respects, particularly in the beating of gold, the practices then developed have not greatly changed to-day; generally, however, the gradual speeding up, caused by increasing demands for shaped products that can be drawn or pressed, has resulted in the greater use of machinery, and by far the greater amount of shaping from sheet is effected by mechanical means.

To facilitate the work of deep drawing and pressing, considerable attention has been given to the development of materials which possess the quality of ductility to such a degree that they show considerable plastic deformation before exhibiting signs of rupture, and during recent years there has been great progress in the development of sheet metal for these operations. It is sometimes denied that any great success has been achieved in this direction, but when the severity of modern methods of production are considered, it will be appreciated that the speed at which pressings are now made would have been impossible with the materials available years ago. Actually, all improvements in the ductile quality of materials have been applied to safe limits as quickly as possible in order to reduce production costs, and defects are bound to be experienced when the ductility of the material confiicts with the speed at which it is desired to press it into shape.

The extent to which deep drawing and pressing operations form the principal methods of manufacture is not generally appreciated, but they are playing a very important part in modern industry. So much has the work of the press shop developed in recent years that it has become a specialised industry with a continually increasing field of application. It is not surprising therefore that this book dealing with the subject has been published, but that it might have been usefully published years ago. Fortunately, the author has not been content to deal only with pressing operations, but has been at great pains to present information of a comprehensive character covering the manufacture of deep drawing materials, methods of testing, defects and difficulties encountered, presses, tools, etc., used and the various operations involved in press-work. Both ferrous and non-ferrous materials are discussed at considerable length, attention being directed particularly to those factors which influence pressing operations.

Much requires to be done before our knowledge of the mechanism of plastic flow can be regarded other than limited, but whatever the future may hold it is only possible to base press-tool design and press-shop practice on present knowledge, and the author has succeeded in combining both scientific and practical knowledge on deep drawing that will be invaluable to all engaged in the industry. The work is intended for both the practical worker and the scientific student, but all directly concerned with deep drawing and pressing will find it full of valuable information on the subject. The book is well printed and admirably illustrated and contains two appendices—one on the need for definition of terms and the other on the application of X-ray examination,—a list of references and an adequate index.

By J. Dudley Jevrons, Ph.D., B.Sc., A.I.C., with a Foreword by Dr. H. W. Swift; published by Messrs. Chapman and Hall, Ltd., 11, Henrietta Street, Covent Garden, London, W.C. 2.; price 50s. net.

New Dictionary of Chemistry

THE rapid advance of chemical science in its main branches of inorganic, organic and physical chemistry, and the many notable discoveries now being made along the border lines of chemistry, biology and pathology, involve rapid additions to the subject matter of these related sciences. These extensions lead to new methods of description and designation, which sometimes alter rather rapidly. With a view to clarifying the position, the author, with the assistance of many well-known chemists, has compiled this new dictionary in a single handy volume of 575 pages, and has been able to compress in this relatively small space a remarkable amount of accurate information.

The chemical elements are each included in a separate entry, and the entire series is reviewed from several angles under such headings as the elements and their electrons, isotopes, and the periodic table. The more-important compounds of these elements are also surveyed, and in certain typical instances their crystal structures are revealed by X-ray analysis and are indicated by appropriate diagrams. A judicious selection has been made of the more-representative mineral species.

The chemist will find this book a mine of valuable information, while those who are not chemists and yet desire to know the meaning of chemical terms and facts about well-known chemical substances will find it especially useful. In addition to chemical terms the book contains biographical notes on many past and living chemists, and articles which give the latest information about chemical theories and problems of the day as well as the recent developments in biochemistry and chemical engineering. This work is admirably adapted to the needs of the school and college libraries, and for reference to by all studying or teaching the various science subjects.

Edited by Stephen Miall, LL.D., B.Sc., with the assistance of a panel of well-known chemists; published by Longmans, Green and Co., Ltd., 39, Paternoster Row, London, E.C. 4. Price 42s. net.

WIDESPREAD interest in the high nickel-alloy steels is indicated by the contents of the June issue of the *Nickel Bulletin*. Silver additions to 18/8 chromium-nickel steels are now being made to improve machinability. Causes of pitting are being investigated. Work on electrolytic polishing is also described at some length. Copies may be obtained from the Bureau of Information on Nickel, Thames House, Millbank, S.W. 1.

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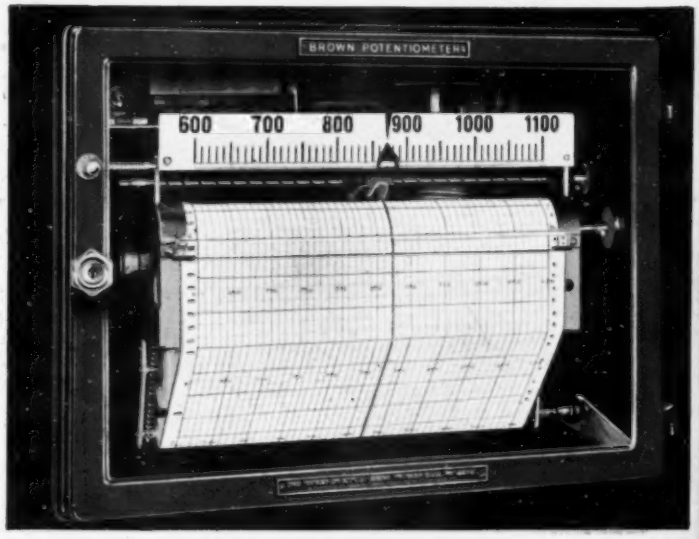

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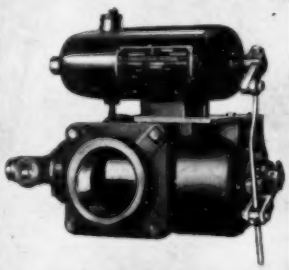

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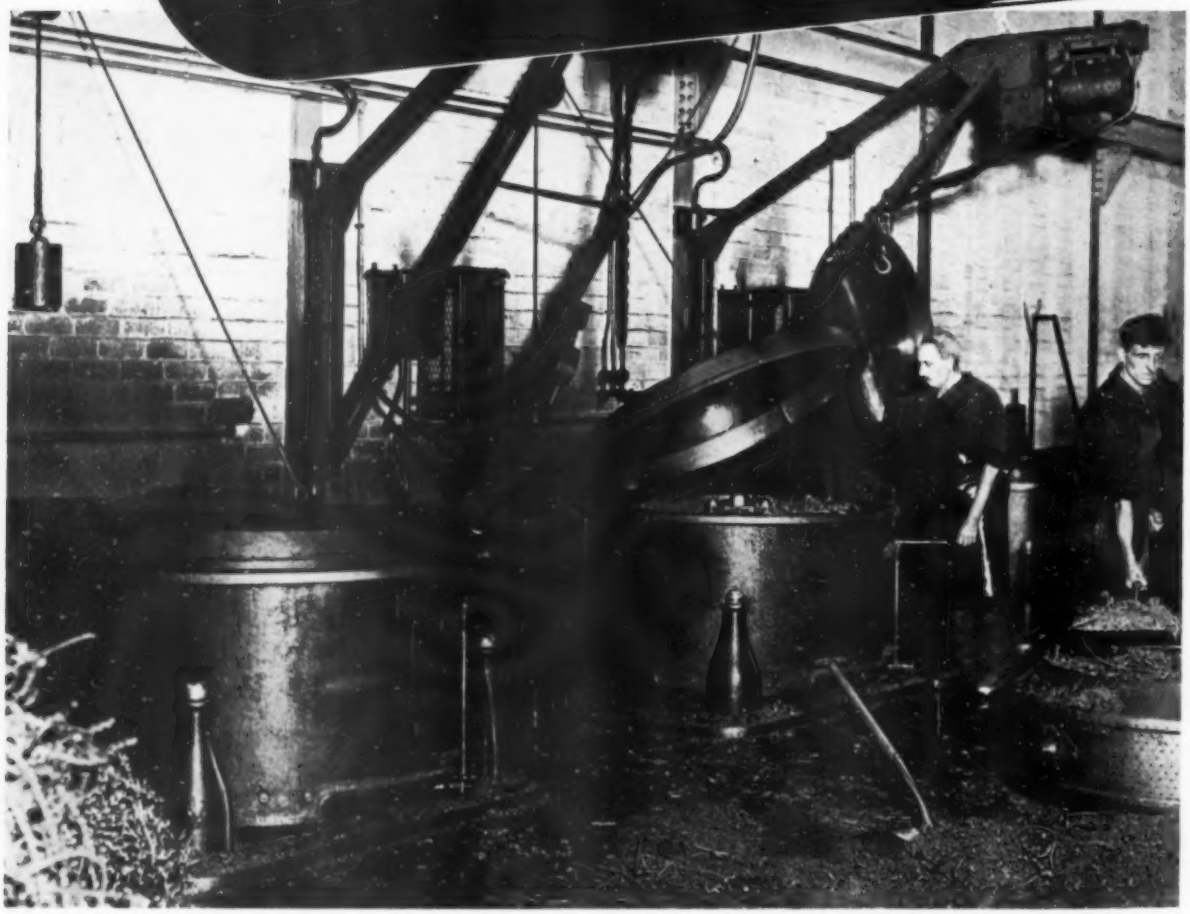

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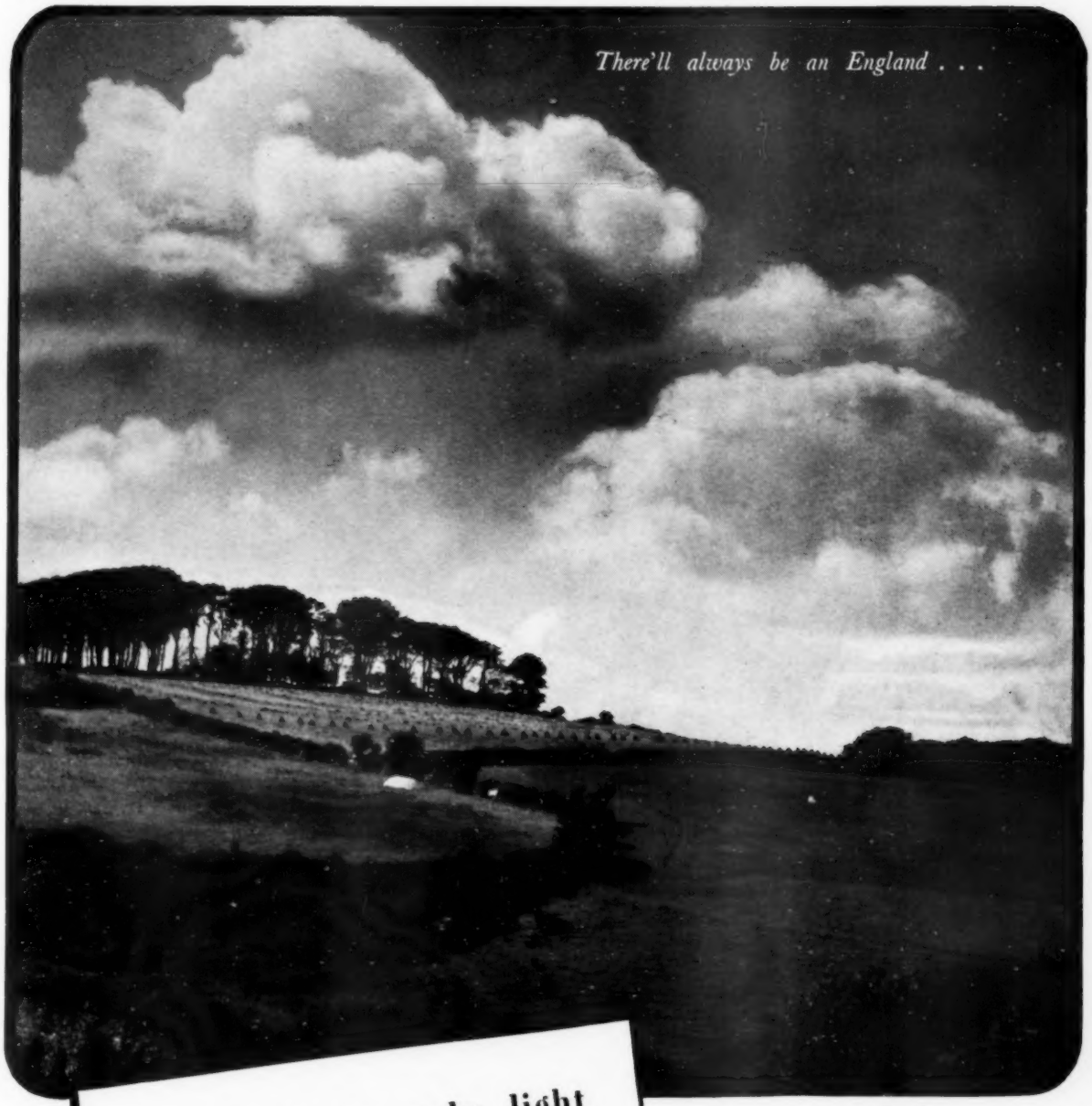

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